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DEVELOPMENT DIGEST

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CONTENTS

Volume XIII - Number 2 April 1975

MIGRATION

MIGRATION MATTERS 3
Nancy Birdsall

POLICIES AFFECTING RURAL-URBAN MIGRATION IN AFRICA 8
Michael P. Todaro

LAND TENURE AND THE RURAL EXODUS IN LATIN AMERICA 24
R. Paul Shaw

URBANIZATION AND MIGRATION IN TAIWAN 32
Alden Speare, Jr.

MIXTEC MIGRANTS IN MEXICO CITY 40
Carlos L. Orellana

THE SAHEL

THE DROUGHT IN WEST AFRICA 49
Victor D. DuBois

DISASTER RELIEF IN THE SAHEL 62
Organization for Economic Cooperation and Development (OECD), Development Advisory Committee (DAC)

A SECTORAL APPROACH TO THE CATTLE INDUSTRY IN WEST AFRICA 70
Frank D. Abercrombie

AGRICULTURAL PRODUCTION IN MALI 81
Martin Billings

WATER TECHNOLOGIES FOR ARID LANDS

MORE WATER FOR ARID LANDS 93
National Academy of Sciences

CORRECTION: In the Development Digest of October 1974 the authorship of the article entitled, "Television Programming in Dakar," on pp. 90-102, was attributed to the UNESCO staff. In fact this article was written for UNESCO by Dr. Henry R. Cassirer, formerly with the UNESCO staff and currently a consultant in Annecy, France.

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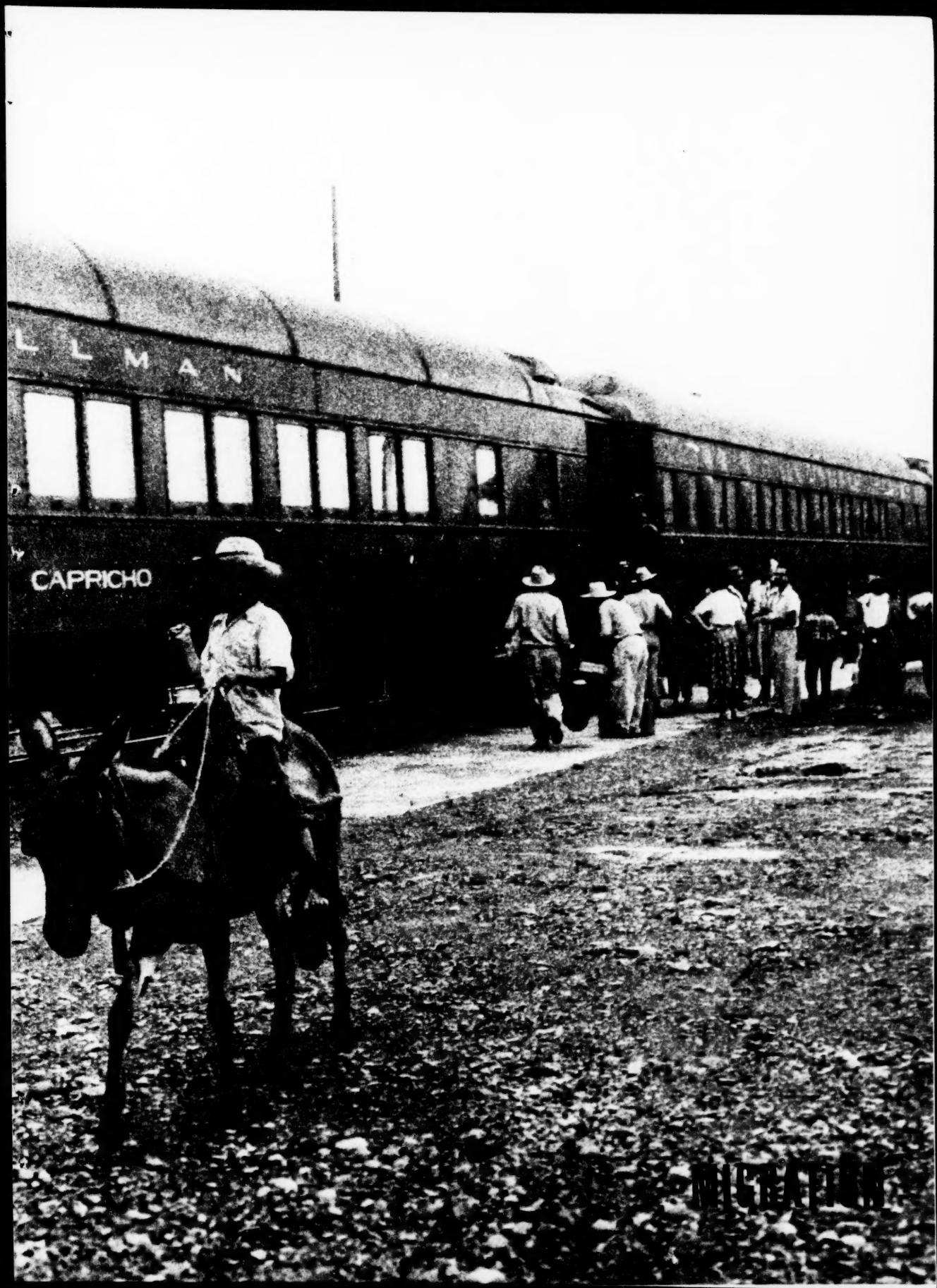
L L M A N
CAPRICHO

COUNTRY PEOPLE BOARDING A TRAIN
IN CULIACAN, MEXICO

[PHOTO: WORLD BANK.]

Migration Matters

Nancy Birdsall

[Migration from rural areas to towns and cities has a number of important consequences for development. Migration research has been primarily descriptive rather than geared to the needs of development planners and policymakers. Policy-relevant research on migration requires new conceptual and data-gathering approaches.]

"How you going to keep 'em down on the farm?" is not a new topic, nor one confined to any one type of country. While world population increased by about 20 percent from 1960 to 1970, the world's urban population increased by about 40 percent; the proportion classfied as urban rose from 33 to 40 percent. Development planners and government decisionmakers are concerned about the observable and potential ill effects of heavy rural-urban migration for overcrowded cities and underproductive rural areas. The decision to move is a private or family one; few governments are willing or able to restrict this freedom absolutely. The search is for ways to alter private decisions through public policies, such as improved services in rural areas and better information on urban opportunities, and for ways to increase the relative returns to agriculture vs. urban wage labor.

Migration matters because it affects the essential ingredients of "development" in poor countries: rural development, alleviation of urban poverty, and improved distribution of income. Scholars have not neglected the subject. Characteristics of migrants, their

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reasons for moving, and their fate in the cities have been amply described. But migration research has rarely been helpful to policy-makers. Diagnosis has not been followed by useful prescription. Policy analysis is the next step. This essay will review the link between migration and development goals; summarize briefly what we know about the subject; and discuss the requirements for a new policy direction for migration research.

Migration may inhibit rural development by drawing high-quality labor to cities; if it does so without an offsetting improvement in urban development, it is economically inefficient, reducing the overall growth of a nation's economy. An exodus of high-quality labor from rural areas may arise from market imperfections which put the private cost of migration below the social cost. Urban wages for a lucky few may be maintained at an artifically high level because of minimum wage legislation or government hiring. Farm income may be artifically low because of undervaluation of agricultural products through fiscal and marketing board policies, e. g., export taxes on cash crops like cotton and coffee or controls on prices of food crops as a subsidy to the urban poor. Urban-oriented curricula in rural schools may induce the brightest students to leave home, thus transferring a rural investment in human capital to an urban area, a type of in-country "brain-drain," or "internal colonialism," a term made popular of late by Latin American sociologists.

Migration need not be inefficient for development. In countries where rural labor is unproductive and more productive urban jobs are available, migration provides a valuable link between rural and urban labor markets. Such a view guides the regional development strategy of Colombia and Tanzania. Even countries seeking to restrain rural-urban migration do not dream of eliminating it.

But even in countries where there is surplus agricultural labor, urban unemployment and underemployment is often high. Though cities have grown by as much as 14 percent a year in Africa since World War II, implying a seven percent annual increase in the urban labor force, non-agricultural wage employment has grown by less than five percent annually in most countries. Estimates of unemployment in Sub-Saharan African cities range between 10 and 50 percent. (African conditions may be somewhat more extreme in these respects than elsewhere, but not wholly different.)

Government measures to reduce unemployment by providing new urban jobs may, in the conditions described, simply induce higher rates of in-migration with uncertain net results for the number unemployed. Similarly, government efforts to alleviate the worst forms of urban poverty through subsidization of housing, increases in health and education, or the provision of sanitary services may also persuade more of the rural poor to move.

Migration may also affect income distribution. In-country income differentials throughout the less developed world are great between urban and rural areas, and probably substantial within urban areas between those working in the formal wage and salary sector, and those unemployed or marginally employed. If migration adversely affects rural development, or simply adds to the numbers of urban unemployed, it can exacerbate income differentials.

We know much about migrants and the migration process. Most migrants are young (under 30); they are usually better educated than those who stay in rural areas; their choice of destination is influenced positively by the presence of friends and relatives, and negatively by distance. In Africa and Asia more migrants are men; in Latin America more are women.

Most migrants who stay do find jobs, and they consider themselves better-off economically. After some period of time, there are in fact few employment differences between migrants and non-migrants of similar age, education and sex. However, surveys of migrants in cities capture only those who stayed; those failing to get jobs may have left. Migration out of cities is sometimes substantial (Taipei City had four out-migrants for every five in-migrants between 1959 and 1968 — this is probably an unusually high ratio); many in-migrants come from other urban areas (as high as 50 percent in Delhi); and many persons move back to their original villages (after age 45 returning migrants exceed out-migrants in rural areas in Kenya).

Economic motives are paramount in the decision to move. When persons are asked why they moved, they most frequently cite better employment opportunities and higher income as their primary reasons. Econometric studies confirm that rural-urban income differentials explain much of the variation in migration rates from different areas. This remains true when the urban wage rate is adjusted for the probability of being employed, demonstrating that persons are not unaware of possible difficulty in obtaining a job. Even more variation is explained when some measure of the probability of finding work in the informal (as opposed to wage) sector is also included. However, a number of studies have shown rather low correlations, or give inconclusive results due to weaknesses in the data.

Furthermore, other known facts about migrants may be indirectly explained by economic realities. The young are more likely to move than older people because for them the benefit of higher income will accumulate over a longer period to offset the cost of moving. The better educated are more likely to move because returns to education are higher in the cities, a reflection in some degree of the urban orientation of school curricula. Migrants choose destinations where relatives are living since relatives can provide temporary free housing and job contacts (thus reducing the costs of moving and improving job prospects).

But existing knowledge of migration is for the most part inadequate for policy purposes. Policy analysis requires 1) that the individual decision to migrate be studied in terms of variables which are manipulable by the government, and 2) that analysis go beyond description to hypothesis-testing and quantification.

Consider the first requirement. What public policies inadvertently or deliberately affect private migration decisions? These can include policies unrelated to migration per se but directed toward general development goals, e. g., increasing credit availability in rural areas, provision of more jobs in cities, provision of more services to the urban poor, minimum wage legislation. Attitudinal studies of migration have not isolated which among these economic policy variables influence movers, nor established their relative values for different groups of movers. For example, what is the relative importanceof urban jobs vs. the free urban services (which add to the migrant's real income) in the mover's "economic" decision?

Consider the second requirement. Hypotheses should be constructed and tested which quantify a relationship between a "policy variable" and migration. If migrants move to increase their income, what is the critical minimum level of income differential between a given rural region and a given city beyond which a move is induced? By how much does this critical minimum differ according to the existence of certain services in rural areas, such as electricity, schools and clinics?

Quantification is accomplished through estimation of elasticities. Elasticities offer a specific prediction that a stated percentage change in an independent policy variable will produce a given percentage change in migration. In the case of migration analysis, the objective would be to quantify the elasticity of response of migrants to chosen "policy variables." For example, what would be the elasticity of response of migration to a given increase in the urban wage rate, all other things being equal? Or to a given increase in land availability through land reform? What would be the effect on migration rates of a combination of these and other development policies?

Knowledge of migration elasticities should also influence decisions regarding urban sectoral investments, decisions regarding both the feasibility of specific projects and their location. High urban unemployment might suggest that the shadow price of labor should be treated as zero; however, the true labor cost would be higher if urban projects were to induce migration of non-surplus agricultural labor.

Economists have conducted studies which partially fulfill the above requirements. Unfortunately the only policy variables considered in

most studies are wages and the rate of employment. Using regression techniques, estimates are made of the elasticity of response of migration to differentials in wages and in employment among various origin-destination point combinations. Most of these studies are cross-sectional rather than time-series, often because there are not reliably comparable time series in the available census figures; thus comparison of migration from one place to another over time is impossible. Also, they almost invariably rely on census data in which the migration variable that can be obtained is interstate or interregional population movement, rather than rural-uban flows, misses intraregional shifts, and cannot identify movers by age, sex and education — all critical variables. These studies demonstrate that policy-relevant migration research will require the generation of more kinds of data through specially-designed surveys. Such data will need to include average wage and income levels in both origin and destination areas, as well as changes in income of movers and non-movers. To test other policy variables, such as the effect of increased education in rural and/or urban areas, of new agricultural credit or of new urban housing, data on these possible determinants of migration should also be collected. Future migration research will thus optimally be carried out in conjunction with household budget and expenditure surveys and with farm management and production surveys.

A few research programs are now carrying out policy analysis of migration. The African Rural Employment Study under the direction of Carl Eicher at Michigan State University has produced a number of papers identifying the critical policy relationships between rural employment problems and migration; for example, they are presently studying migration in Sierra Leone in conjunction with an intensive farm management survey. The World Bank Urban Poverty Task Force is concerned with the policy relationship between migration and urban problems. These and other research programs demonstrate that policy-relevant analysis of migration requires the combined efforts of scholars in such diverse fields as agriculture, urban planning, anthropology, geography and economics.

Certainly migration matters. In Africa and parts of Latin America and Asia there is still time for governments to plan rational regional and urban development. Improved understanding of the private motivations which stimulate migration will permit rational design of public policies to maximize congruence between the welfare of individuals and the general public welfare.

[Unpublished paper, January 1975.]

Policies Affecting Rural-Urban Migration in Africa

Michael P. Todaro

[The rapid rural-to-urban migration rates common in sub-Saharan Africa continue despite rising unemployment in cities, with various negative consequences for development. An analysis of causes for this is presented, followed by a systematic examination of the possible policies for reducing unemployment in light of the analysis.]

In the years since independence, the nations of tropical Africa have experienced an unprecedented increase in the size of their urban populations. From Abidjan to Brazzaville to Nairobi, recorded urban population growth rates of 7 to 10 percent per annum are a common phenomenon (see table I). The most important source of this growth has been the massive increase in the number of migrants arriving from surrounding rural areas. Numerous factors, both economic and non-economic, underlie the decision of peasant farmers and educated youths to seek the "better life" in the rapidly growing urban centers.

Rural-urban migration is by no means an undesirable phenomenon. Most of the theories of economic development, based largely on the historical experience of Western industrialized nations, emphasize the transformation of an economy from a rural agrarian base to one with an industrial, urban focus. This is made possible by the continuous absorption of "surplus" rural laborers into the growing industrial economy. Ideally, the rate of growth of modern industries then provides a sufficient number of newly created employment opportunities. Unfortunately, real world conditions do not always conform to the economist's development scenario.

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TABLE I. SUB-SAHARAN AFRICA: URBAN POPULATION GROWTH

City	Year	Population ('000)	Year	Population ('000)		Annual growth (%)	
				City proper	Urban agglom-eration	City proper	Urban agglom-eration
Salisbury	1946	69	1966		330		8.1
Dar es Salaam	1948	69	1967	273		7.5	
Brazzaville	1955	76	1961-62		136		8.7
Dakar	1945	132	1961		375		6.7
Accra	1948	136	1963	616	758	7.8	8.1
Nairobi	1948	119	1968		479		7.2
Abidjan	1955	127	1964		282		9.3
Monrovia	1956	41	1962	81		11.9	
Fort Lamy	1955	29	1964		99		13.6
Cotonou	1945	26	1965	111		7.5	
Mombasa	1948	85	1968		234		5.2
Bamako	1945	37	1965		165		7.8
Bulawayo	1946	53	1966		240		7.8
Lusaka	1950	26	1966		152		11.7
Yaoundé	1955	38	1965	101		10.3	
Douala	1954	118	1965		200		4.9
Addis Ababa	1951	400	1967	644		3.0	
Khartoum-Omdurman	1948	210	1967	390		3.3	
Luanda	1950	150	1960		225		4.1
Léopoldville (Kinshasa)	1946	110	1966	508		8.0	
Elisabethville (Lubumbashi)	1950	103	1966	233		5.2	
Kumasi	1955	75	1968	282	340	10.7	12.3
Lourenco-Marques	1950	94	1960		179		6.7

Sources: United Nations: Demographic yearbook (New York), various issues; and William A. Hance: The geography of modern Africa (New York, Columbia University Press, 1964), p. 54.

In tropical Africa the magnitude of rural-urban migration has greatly exceeded the capacity of the modern industrial sector to absorb the persons concerned, so that it can only employ productively a small proportion of them. Part of the problem relates to the nature of African industrailization, a process which has typically failed to produce a growth of job opportunities at anything near the rate of output growth. If one uses the standard criterion of output growth as the measuring rod for success, many African economies with output growth rates of 5 to 8 percent per annum have done rather well under the circumstances. However, as table II reveals, the growth rate of non-agricultural employment has typically been negligible and, in many cases, negative.

It is in this context of slowly growing urban employment opportunities accompanied by a disproportionately high rate of rural-urban migration that the chronic urban unemployment and underemployment problem has emerged in tropical Africa. Although there are few hard

data on the magnitude of African urban unemployment, owing both to conceptual difficulties in defining unemployment and, more importantly, to the fact that very few studies have been directed to the problem, the limited evidence available provides ample empirical confirmation of what any informed observer already knows — namely that urban unemployment is an extremely serious problem (see table III for a summary of available data on urban unemployment rates in African cities). However, inspite of these rising levels of overt unemployment and even higher levels of underemployment, the rate of rural-urban migration shows no sign of deceleration. To the extent that many newly arrived migrants are likely to join the growing pools of unemployed and highly underemployed workers, and to the extent that an increasingly large proportion of these migrants represent the more educated segments of society whose productive potential is largely being dissipated, the process of continued rural-urban migration at present levels can no longer be said to represent a desirable economic phenomenon. Until something positive is done to relieve this problem, the African development effort will be only partially successful.

TABLE II. NON-AGRICULTURAL EMPLOYMENT INDICES IN SELECTED AFRICAN COUNTRIES, 1955-64

(1958 = 100)

Year	Cameroon	Ghana[1]	Kenya	Malawi	Nigeria
1955	102	82	107	88	n.a.
1956	104	91	105	95	95
1957	100	95	105	98	100
1958	100	100	100	100	100
1959	95	106	100	99	99
1960	91	111	102	96	106
1961	94	122	98	93	89
1962	72	128	97	87	113
1963	91	132	91	87	94
1964	92	n.a.	101	n.a.	n.a.
Rate of growth (%)	—1.0	6.3	—0.5	—0.7	0.1

Year	Sierra Leone	Southern Rhodesia	Tanzania	Uganda	Zambia
1955	87	86	97	94	92
1956	87	92	104	93	100
1957	92	98	101	99	100
1958	100	100	100	100	100
1959	98	100	96	99	95
1960	101	101	98	99	93
1961	108	98	104	98	90
1962	112	95	101	93	88
1963	119	91	91	89	86
1964	125	90	95	89	91
Rate of growth (%)	3.0	0.2	—0.4	—0.1	—0.9

[1]Note that the relatively high rate of Ghanaian employment growth in the late 1950s and early 1960s was due primarily to the rapid increase in public employment as a result of Nkrumah's "make-work" policy. In the years since 1964, employment growth in Ghana has been negligible since the "make-work" policy could not be sustained for long without undue fiscal strain.

Source: Charles R. Frank, Jr.: Urban unemployment and economic growth in Africa, Economic Growth Center Paper No. 120 (New Haven, (Connecticut), 1968), p. 254.

TABLE III. URBAN UNEMPLOYMENT RATES IN AFRICA

(%)

Country (urban centers)	Unemployment rate	Country (urban centers)	Unemployment rate
Algeria (1966)	26.6	Kenya (1969)	
Cameroon (1966)		Eight urban areas	17.4
Douala	13.0	Morocco (1960)	20.5
Yaoundé	17.0	Nigeria (1963)	
Congo (1958)		Lagos	15.5
Léopoldville (Kinshasa)	15.0	Ife	19.7
Ghana (1960)		Onitsha	26.3
Large towns	11.6	Kaduna	30.8
Ivory Coast (1963)		Abeokuta	34.6
Abidjan	20.0	Tanzania (1965)	12.6

Sources: Algeria, Ghana, Morocco and Tanzania — D. Turnham: The employment problem in less developed countries: a review of evidence (Paris, OECD Development Center, 1970), pp. 193-195. Cameroon and Ivory Coast — Remi Clignet: "Preliminary notes of a study of unemployment in modern African urban centers," in Manpower and unemployment research in Africa, Vol. 2, April 1969. Nigeria — Peter C. W. Gutkind: "The energy of despair: social organization of the unemployed in two African cities: Lagos and Nairobi," in Civilizations (Brussels), Vol. XVII, 1967, No. 3, pp. 186-211, and No. 4, pp. 380-402. Congo — P. Raymachers: Etude par sondage de la main-d' auvre à Léopoldville (Ministère du Plan et de la coopération économique, 1958). Kenya — H. Rempel and M. P. Todaro: "Rural-urban labor migration in Kenya: some preliminary findings of a large-scale survey," in S. Ominde (ed.): Population growth and economic development (to be published).

A Theoretical Framework for Analyzing the Economics of Rural-Urban Migration in Africa

I would like to set forth briefly a theoretical framework which yields some important insights into the causes and mechanisms of rural-urban migration in tropical Africa. No attempt will be made to describe this model in any great detail since that has been done elsewhere (e. g. in the American Economic Review, March 1969, pp. 138-48). This will serve two purposes: first, to demonstrate why the continued existence of rural-urban migration in the face of rising levels of urban unemployment often represents a rational economic decision from the point of view of the private individual; and second, to demonstrate how such a theoretical framework can be used in an analysis and evaluation of alternative public policies to alleviate the growing urban unemployment problem.

The individual decision to migrate: some behavioral assumptions. The basic behavioral assumption of the model is that each potential migrant decides whether or not to move to the city on the basis of an implicit "expected" income maximization objective. There are two principal economic factors involved in this decision to migrate. The first relates to the existing urban-rural real wage differential that

prevails for different skill and educational categories of workers. There are large disparities between wages paid to urban workers and those paid to comparably skilled rural laborers. The increasing divergence between urban and rural incomes has arisen both as a result of the relative stagnation of agricultural earnings (partly as a direct outgrowth of post-war bias toward industrialization at the expense of agricultural expansion) and the concomitant phenomenon of rapidly rising urban wage rates for unskilled workers. For example, in Nigeria Arthur Lewis noted that "urban wages" are typically at levels twice as high as average farm incomes. Between 1950 and 1963 prices received by farmers through marketing boards in southern Nigeria fell by 25 percent while at the same time the minimum wage scales of the Federal Government increased by 200 percent. In Kenya average earnings of African employees in the non-agricultural sector rose from £97 in 1960 to £180 in 1966, while the small farm sector experienced a growth of estimated family income of only 5 percent per annum, rising from £57 in 1960 to £77 in 1966. And in Uganda, from 1954 to 1964, agricultural incomes remained essentially unchanged while minimum wages in government employment in Kampala rose by almost 200 percent from £31 to £90 per annum. It should be noted that in Uganda as in most other African nations the minimum wage often acts as the effective rate which determines the level at which more than 50 percent of urban unskilled workers are paid. It is also the key weight in the overall wage structure since, when the minimum wage changes, the entire wage structure tends to move with it.

The second crucial element in the analysis relates to the degree of probability that a migrant will be successful in securing an urban job. Without introducing the probability variable it would be extremely difficult to explain the continued and often accelerated rate of migration in the face of sizeable and growing pools of urban unemployed. The key, in my opinion, to an understanding of the seemingly paradoxical phenomenon lies in viewing the migration process from an "expected" or permanent income approach where expected income relates not only to the actual wage paid to an urban worker, but also to the probability that he will be successful in securing wage employment in any given period of time. It is the combination and interaction of these two variables — the urban-rural real income differential and the probability of securing an urban job — which I believe determine the rate and magnitude of rural-urban migration in tropical Africa.

Suppose the average unskilled or semi-skilled rural worker has a choice between being a farm laborer or working his own land for an annual average real income of, say, 50 units, or migrating to the city where a worker with his skill or educational background can obtain wage employment yielding an annual real income of 100 units. The more commonly used economic models of migration, which place exclusive emphasis on the income differential factor as the determinant of the decision to migrate, would indicate a clear choice in this situation:

the worker should seek the higher-paying urban job. It is important to recognize, however, that these migration models were developed largely in the context of advanced industrial economies and, as such, implicitly assume the existence of full employment or near-full employment. Simple economic theory would then indicate that such migration should lead to a reduction in wage differentials through the interaction of the forces of supply and demand, both in areas of out-migration and in points of in-migration.

Unfortunately, such an analysis is not very realistic in the context of the institutional and economic framework of most of the nations of tropical Africa. First of all, these countries are beset by a chronic and serious unemployment problem with the result that a typical migrant cannot expect to secure a high-paying urban job immediately. In fact, it is much more likely that upon entering the urban labor market the migrant will either become totally unemployed or will seek casual and part-time employment in the urban traditional sector. Consequently, in his decision to migrate the individual in effect must balance the probabilities and risks of being unemployed or underemployed for a considerable period of time against the positive urban-rural real income differential. The fact that a typical migrant can expect to earn twice the annual real income in an urban area that he can in a rural environment may be of little consequence if his actual probability of securing the higher-paying job within, say, a one-year period is one chance in five. In such a situation we could say that his actual probability of being successful in securing the higher-paying urban job is 20 percent, so that his "expected" urban income for the one-year period is in fact 20 units and not the 100 units that the fully employed urban worker receives. Thus, with a one-period time horizon and a probability of success of 20 percent it would be irrational for this migrant to seek an urban job even though the differential between urban and rural earnings capacity is 100 percent. On the other hand, if the probability of success were, say, 60 percent, so that the expected urban income is 60 units, then it would be entirely rational for an out-migrant with his one-period time horizon to try his luck in the urban area even though urban unemployment may be extremely high.

If we now approach the situation more realistically by assuming a considerably longer time horizon, especially in view of the fact that the vast majority of migrants are between the ages of 15 and 23 years, then the decision to migrate should be represented on the basis of a longer-term, more permanent income calculation. If the migrant anticipates a relatively low probability of finding regular wage employment in the initial period but expects this probability to increase over time as he is able to broaden his urban contacts, then it would still be rational for him to migrate even though expected urban income during the initial period or periods might be lower than expected rural income. As long as the present value of the net stream of expected urban income over the migrant's planning horizon exceeds that of the

expected rural income, the decision to migrate is justified. The mathematical details of our model of rural-urban migration [omitted here] indicate the conditions under which the urban-rural "expected" income differential can act to exacerbate the urban unemployment situation, even though urban employment might expand as a direct result of government policy. It all depends on the relationship between migration flows and the expected income differential as expressed in an "elasticity of migration response," a term developed in the model.

Since the elasticity of response will itself be directly related to the probability of finding a job and the size of the urban-rural real income differential, the model illustrates the paradox of a completely urban solution to the urban unemployment problem. Policies which operate solely on urban labor demand are not likely to be of much assistance in reducing urban unemployment since, in accordance with our expected income hypothesis, the growth of urban employment ceteris paribus also increases the rate of rural-urban migration. If the increase in the growth of the urban labor force caused by migration exceeds the increase in the growth of employment, the level of unemployment in absolute numbers will increase and the unemployment rate itself might also increase. This result will be accentuated if, for any increase in job creation, the urban real wage is permitted to expand at a greater rate than rural real income. A reduction or at least a slow growth in urban wages, therefore, has a dual beneficial effect in that it tends to reduce the rate of rural-urban migration and increase the demand for labor.

Let us turn now to an examination of alternative policies which might be adopted to relieve the serious urban unemployment problem in tropical African nations. Since the problem has short, intermediate and long-range dimensions, and since there is a wide range of policies available some of which can have a more immediate impact than others, I shall first look into policies that are likely to have quicker results, followed by those whose effects may be more of an intermediate or long-term nature.

Short Run Policies

1. Eliminating factor-price distortions. It is now becoming painfully apparent that past policies which gave top priority to the rapid accumulation of capital as the key to successful economic progress in the 1950s and early 1960s have led to the serious employment predicament of the 1970s. Typically, a spectrum of policy devices ranging from overvalued exchange rates to accelerated capital depreciation allowances, tax rebates, licensing agreements, and negative effective rates of protection for imported capital goods was instituted, which effectively pushed the price of capital well below its real opportunity cost. On the other hand, in their natural and understandable desire to raise the standard of living of their working populations, African governments acquiesced to pressure both from trade unions and civil servants in setting

urban wage rates at levels considerably in excess of rural average incomes and the over-all opportunity cost of urban labor.

This combination of underpriced capital and overpriced labor has no doubt been a factor in retarding the expansion of urban employment opportunities by encouraging capital-labor substitution in the production process. Moreover, this implicit bias towards relatively capital-intensive methods of production has been aided and abetted by the policies of national aid agencies which tie large proportions of their aid to the importation of their own nation's capital equipment. The impact of this distorted factor-price structure is felt not only in urban areas where sophisticated modern equipment is being installed in almost all newly established industries, but also in rural agricultural areas where premature tractor mechanization is being encouraged by similar policies relating to the importation of farm machinery. These policies have also contributed to the influx of rural migrants in spite of the relatively slow growth of urban job openings. By mechanizing their production efforts, employers in the modern sector are able to offer relatively high wages for their limited number of employees, and unions are able to justify these high wages on the basis of rising levels of labor productivity.

It follows that one of the most immediate and pressing short-run policies that needs to be given serious consideration is one which attempts to "clear the decks" by eliminating factor-price distortions that inhibit increased labor absorption. In fact, given the pressing need for more employment creation from a political standpoint, one might even argue that governments should consider the advisability of even distorting factor prices in the opposite direction. This could be achieved by discouraging the further importation of highly capital-intensive equipment, by forcing the price of capital above its real opportunity cost, and reducing the effective labor price to producers.

2. Wage subsidies and wage restraint. One of the principal mechanisms for the partial elimination of factor-price distortions and the encouragement of more labor-intensive practices is the establishment of some form of "dual" wage structure that incorporates wage subsidies as part of an over-all employment-generating strategy. Subsidies which lower the effective level of compensation that employers must pay their employees should have a stimulating employment effect so long as the wage elasticity of demand for labor is reasonably positive. A number of recent studies have confirmed the existence of such a positive elasticity. For example, in a study of wages, employment and productivity in Kenya it was estimated that in the manufacturing sector of Kenyan industry the wage elasticity of demand for labor was approximately 0. 76 indicating that a 10 percent reduction in wage costs for employers will stimulate a 7 1/2 percent increase in employment opportunities. Since a good proportion of the subsidy payments will

be returned to the government in the form of higher taxation, corporate and personal, it is reasonable to expect that a system of wage subsidies can operate somewhat in the manner of the traditional wages fund.

Unfortunately, one of the problems associated with any system of wage subsidies is that the actual wage paid to the employee will still be in excess of labor's opportunity cost. The result is that the higher wage will be paid to a larger proportion of the urban workforce, which in turn increases the probability that a typical migrant will be successful in securing a job. Using the model of rural-urban migration, I demonstrated earlier how such a situation could then lead to a worsening of the urban unemployment through increased migration even though more urban employment might be created.

It is essential, therefore, that any wage subsidy program be accompanied by a general policy of wage restraint. Otherwise, the total effect of the subsidy might be negated by rising levels of overall wages. From a strictly economic viewpoint, what is probably needed is a general reduction in overall wages, but the political realities of developing nations usually preclude such a possibility. Nevertheless, a policy of wage restraint will tend to reduce the rate of rural-urban migration and increase the demand for employment. Without wage restraint, efforts to stimulate employment by reducing the capital-labor ratio through the elimination of some of the factor-price distortions referred to above can only have a limited success in reducing urban unemployment.

3. Employment creation by voluntary agreement. Another short-term policy which has attracted considerable interest was the effort on the part of the Government of Kenya in 1964 to stimulate immediate employment creation through a Tripartite Agreement between itself, employers, and the trade unions. Under this Agreement, the Government and the employers were to increase their total employment by 15 percent and 10 percent respectively, while the trade unions, for their part, agreed to hold the line on all wage demands for a twelve-month period. Upon expiry the Agreement was extended for an additional three months. While no detailed study of this most interesting experiment has been undertaken, it is widely believed that the Tripartite Agreement did not have any lasting long-term effect on employment generation. For example, Professor Dharam Ghai of the Institute for Development Studies in Nairobi made the following observations on the 1964 Tripartite Agreement:

"Owing to financial stringency, the Government found itself unable to carry out its pledge. In all, 34,000 jobs were found for persons who were either landless or previously unemployed. But it is doubtful whether these represented a net increase in employment; for while many of the private firms adhered to the letter of the agreement by taking on more employees, they violated its intent by not hiring new employees to make good the loss

caused by normal attrition of the labor force. Furthermore, even if the agreement was successful in creating some new jobs, it did not make any particular impact on the level of urban unemployment, for prospects of wage employment stimulated an additional flow of migrants from the rural areas. It is clear that policies of this nature can create additional employment only in the very short run."

The Tripartite Agreement provides an excellent example of the crucial importance of the probability factor in the decision to migrate. The Agreement effectively increased the probability that a migrant would successfully secure a job while the wage differential was held constant. Our model tells us that in such a situation there should be an accelerated flow of rural-urban migration resulting from the widening of the "expected" income differential even though the actual income differential remains unchanged. This is in fact what happened in Kenya immediately following the announcement of the Agreement, when there was a massive influx from the rural areas of job seekers who had learned of the move to increase employment opportunities. The result of the entire process as pointed out by Ghai, Harbison and others was that actual levels of urban unemployment probably increased whereas the over-all level of employment did not change substantially.

It is interesting to note that in June 1970 the Government of Kenya announced another Tripartite Agreement under which both it and private firms were required to increase their employment rolls by 10 percent. Early reports indicated once again that the net impact of this second attempt at instant employment creation was a further increase in the level of urban unemployment. These observations emphasize the point that when short-run policies are not accompanied by more basic long-run structural changes in the economic system they can have very limited lasting effects.

4. Restrictions on migration. Short-run attempts to ease the urban unemployment problem can also take the form of efforts to restrict the accelerated influx of rural migrants whose chances of securing an urban job are minimal. These policies can range from simple "moral exhortations" to return to the land, as has been intermittenly practiced by the Kenyan Government, to enforced back-to-the-land movements such as that practiced for some time in Tanzania.

Policies of moral suasion have in practice met with very limited success in persuading individuals to abandon their self-interest. A more direct effort to regulate the flow of rural-urban migration, one which forces the urban unemployed to return to their rural areas, has been instituted by the Government of Tanzania. Individuals in urban areas of Tanzania are required to hold cards stamped to show that they are presently employed. If they cannot produce one they are liable to be returned either to their home area in the countryside or to some

other rural location if they are landless. Clearly, if the urban unemployed are individuals who have productive opportunities available to them in rural areas, as most do in the case of Tanzania, the successful repatriation of the unemployed can result in a net increase in national output and thus be socially productive. Tanzania is already experiencing difficulties in keeping the repatriated urban unemployed on farm settlements. This is not too surprising given the substantial expected real earnings differential, even though Tanzania has attempted to hold the line on urban wage increases. Moreover, there has been no real attempt to compensate the repatriated workers.

Recognizing the importance of the probability variable in the decision to migrate and the fact that most migrants are prepared to risk being unemployed for a considerable period of time, Gugler suggests that, instead of letting individual migrants gamble in the hope of being selected, the government should play the lottery for them through the institution of urban labor exchanges. His idea is that if all employment openings were to be channelled through government labor exchanges, these exchanges would be able to give definitive answers to new migrants on whether or not they will be successful in obtaining a job. Those unsuccessful, having been told that there is no employment for them at that time and that they will not be reconsidered at a later time, could thus be persuaded, in Gugler's opinion, to return to their rural homes after a short stay in town. To be successful such a program would need the full cooperation of employers and a high standard of record keeping at the labor exchanges, so that it would be possible to recognize and refuse the man who applied for a second time even though he might change his name.

While this is an intriguing idea and probably a better approach than simple moral suasion, I am extremely doubtful of its practical feasibility. In addition to the severe resource and bookkeeping problems that would be involved, since one would need to have much more than the mere names of rejected migrants, there is the additional and obvious problem of bureaucratic corruption, tribal preferences, and the relinquishment of the individual employer's right to decide who he will hire and who he will not hire. Consequently, of the three short-run approaches to migration restriction, the Tanzanian plan of forced repatriation is probably the most feasible though it too can give rise to serious administrative and political difficulties.

Intermediate-term Policies

1. A comprehensive incomes policy. Any serious attempt to tackle the dual problem of massive rural-urban migration and rising unemployment must have as its primary objective the gradual elimination of the substantial and economically unwarranted differential between urban and rural real earnings capacity. In the absence of effective migration

control, any policy which attempts to stimulate job creation in the urban areas without at the same time attempting to redress the serious imbalance between urban and rural income levels can only result in ultimate frustration, since any increase in jobs created is likely to be offset by a more rapid increase in new job seekers.

The need for a comprehensive national income and wages policy in efforts to generate more employment opportunities, as well as to remove some of the inequities in the distribution of income, has been a subject of considerable recent discussion. Rapidly rising urban wage rates tend to reduce the level of employment or to limit its expansion in a growing economy by exerting financial pressure on employers to economize on the use of labor. In Kenya, recent empirical studies have indicated that a decline in annual increases in urban wage rates from, say, 6 percent to 2 percent would generate approximately 15,000 additional jobs per year. Rising wages also accentuate the urban unemployment problem by stimulating additional rural-urban migration. A program of urban wage restraint should therefore be part of an overall incomes policy.

Since the vast majority of the population of tropical Africa is agrarian-based, it makes considerable economic sense, as well as being more equitable, to attempt to relate the legal minimum wage rates of unskilled workers in paid employment to the average level of agricultural incomes. This is because the minimum wage rate tends to be the most strategic single rate in most African wage structures. The moral case for equity in income distribution is obvious. The economic rationality of such a wage policy is also clear. By eliminating the artificial incentive for disproportionate migration, an effective policy of urban wage realignment can have an important and positive intermediate-term impact on the national output by improving the distribution of income arising from that national output, and generating employment opportunities in both rural and urban areas.

A second aspect of a comprehensive incomes policy directed at the creation of more job opportunities might focus on the use of the tax structure to complement policies of wage restraint in reducing the rural-urban real income differential. Tax concessions can be used to provide incentives to employers to accelerate the marginal rate of labor absorption within their firms as output expands. It is well known that many of the tax structures in contemporary African nations are generally regressive and biased against the agricultural sector in particular. In the absence of a policy of wage restraint or in combination with a policy of gradual wage increases, governments can use their tax powers to reduce the level of effective income differentials. A disproportionately high tax on urban wages, for example, can act as a disincentive to further rural-urban migration in the same way as an actual reduction in money wages. Moreover, if the revenue generated from these and

other taxes on urban business were to be redirected towards the rural sector in rural development projects, then it could be a powerful mechanism for removing some of the present artificial distortions between urban and rural economic opportunities.

Finally, instead of using the tax structure as an incentive for rapid capital accumulation through depreciation guidelines and tax rebates, governments can contribute to the growth of new employment opportunities by instead providing incentives for additional employment creation through these very same tax powers.

2. Accelerating industrial output growth. Implicit in the assumptions of almost all development models currently in use is the belief that industrial output growth will be accompanied by comparable employment growth so that the employment problem will be indirectly solved by the expansion of aggregate output. Unfortunately, most of the evidence on this relationship in less developed countries provides a uniformly consistent picture of a significant employment lag. In the three East African countries this employment lag has not only been significant but for quite a prolonged period (the late 1950s and early 1960s) but there was in fact a negative relationship — i. e. employment in manufacturing actually declined absolutely while output expanded. Numerous reasons can be cited to account for this phenomenon, including the rapid rise in urban wages, the increased mechanization of production, and the improved efficiency of those already employed as a result of learning-by-doing and on-the-job training. Rapid industrial output growth might indeed create more employment opportunities, but it will also accentuate the influx of rural migrants unless simultaneous steps are taken to reduce rural-urban real differentials.

Our intention here is not to denigrate policies designed to expand industrial output as a means of creating more employment opportunities, but to counter some of the unfortunate euphoric assertions made on the subject. Clearly, output expansion is a necessary prerequisite for employment creation. But the type of production technology utilized in achieving it, as well as the industrial composition of the aggregate expansion, can have considerably more impact on the success of employment generation than the mere achievement of the output growth target. More labor-intensive output growth is what is needed, in conjunction with a package of policies to increase the economic attractions of rural life concurrently with the expansion of urban job opportunities.

3. Intensive agricultural and rural development. Policies which operate on the demand side of the urban employment picture are probably less effective in the long run in alleviating the unemployment problem than are policies designed to affect the supply of labor to urban areas. Policies of rural development are crucial in this regard. Close and informed observers of the African scene such as Lewis, Harbison, Eicher,

Frank and Hunter all agree on the central importance of rural and agricultural development if the urban unemployment problem is to be effectively solved. The ultimate objective of improving the unemployment situation is the restoration of a proper balance between rural and urban incomes, and the elimination of ill-conceived government policies which greatly bias development programs towards the urban industrial sector.

A plethora of proposals designed to increase rural real incomes and amenity levels have been advanced in recent years. Some include the provision of amenities such as electricity, piped water, clinics, cinemas, etc., in rural areas so as to reduce the relative attraction of urban centers, particularly for school leavers. Other proposals have included rural settlement schemes, extension services, and training centers. Still others have stressed the importance of locating industry in rural areas to spread non-agricultural employment opportunities. One of the most common suggestions is the creation of extensive schemes for labor-intensive rural works. All these proposals essentially attempt to reduce the urban-rural disparities in real income and thus the magnet effect of the city.

The proposals for extensive rural works are particularly interesting. Such programs would very likely reduce urban-rural real wage gaps in a number of ways. First, individuals could be employed on such projects during non-peak periods in agriculture. They would thus sacrifice less agricultural income in accepting employment of this sort than in migration to urban areas. Furthermore, the effect of the feeder roads, irrigation schemes, dams, etc., built through such programs would be to raise agricultural productivity — thus further reducing real income differentials. In addition, schools, health centers and other amenities could be built. However, programs of this type do require inputs of scarce organizational and financial resources if they are to be successful, and they place substantial burdens on the fiscal system.

There is also considerable scope for output expansion within the agricultural sector itself. Eicher and his colleagues have observed that "Africa's smallholder land tenure system is remarkably labor absorptive provided incentives are available at the farm level." They argue that as long as African governments avoid premature tractor mechanization, anti-export agricultural policies, autarkic food policies, and an overemphasis on government capital-intensive direct production schemes, there is considerable potential for significant increases in labor absorption in the agricultural sector itself. Moreover, they note that it is only a matter of time before the new high-yielding varieties of maize and wheat (and possibly of other food crops), with their dramatic potential for increases in output and income, become widely available and adopted in African nations. With careful

planning, these new technologies of food production can be made directly applicable to small as well as to large farmers.

Long-run Policies

1. Limiting population growth. Although most African nations are not now faced with the severe population pressures that are currently being experienced in parts of Asia, the rate of population growth in Africa is currently the highest in the world. Growth rates in excess of 3 percent per annum are common south of the Sahara. It is only a matter of time before overpopulation becomes clearly visible. A successful program of population control can make a significant contribution over the long run to the ultimate elimination of the problem of unemployment. Increases in the labor force will be reduced. It should not be forgotten that a large number of children can represent a severe drain on a family's financial resources and thus be a deterrent to savings and investment. Recent empirical evidence has shown that savings rates are strongly influenced by dependency ratios which in turn are determined by the rate of population growth. Moreover, a country with a lower rate of population growth has less need to invest its scarce resources in schools, hospitals and other elements of the economic infrastructure, and can divert them to more directly productive projects with lower capital-output ratios and higher rates of per unit labor utilization.

2. Generating domestic labor-intensive technological capabilities. One of the principal inhibiting factors to the success of any long-run program of labor absorption in the urban industrial as well as in the rural agricultural sector is the technological dependence of contemporary African nations on machinery and equipment from the advanced industrial nations. In essence, the developing nations of Africa have no choice but to use the capital-intensive technology which has been developed in, by and for the richer industrial countries and must be imported from them. In addition to the actual equipment, there is a range of complementary factors which give imported technology a capital-intensive rather than a labor-intensive twist. Private foreign investors, as well as aid donors, have tended to emphasize the supply of imported capital equipment of a sophisticated nature for their own projects; and technicians, planners, advisers, contractors and consultants are typically imported from abroad, or trained abroad, or even when trained at home they still tend to be acquainted with the most modern technologies available and are very unfamiliar with alternative possibilities. Finally, the planners, politicians and even the people themselves in developing countries take a natural pride in big and expensive capital structures which are often looked upon as being synonomous with economic development and modernization.

Since the dynamics of technology transfer are such that less developed countries have little or no influence on either the production technique they use today or the technique it would be most desirable to use in the

future, the task of effectively absorbing large increments of the labor force into an over-all framework of industrial and agricultural progress is made that much more difficult. I have argued that the only viable long-run alternative is for the developing countries themselves, either singly or preferably in cooperation, to begin the task of generating their own technology through the creation of a capital goods industry that will be responsive to the unique needs of labor-surplus societies. The creation of indigenous capital goods industries will require for the most part the training of engineers and scientists with creative as well as technological capabilities. It will be a long-run process and will require the cooperation and the technical and financial aid of advanced societies. One possible way of overcoming the initial administrative, financial and skill requirements of such an enterprise might be through the creation of a series of Regional Institutes for the Development of Labor-Intensive Technologies along the lines of the very successful programs sponsored by the Rockefeller and Ford Foundations establishing research institutes for the development of new high-yielding food varieties.

Conclusions

Clearly, what is needed if any real impact is to be made on the unemployment problem is not a single policy but a "package" of policies, including those whose effects are more immediate as well as those whose impact will be felt in the longer run. If I were asked to identify and put together such a package of policies, my inclination would be to argue for the immediate elimination of factor-price distortions, especially with regard to the price of capital; a comprehensive incomes policy in which urban wage restraint is an important element; a redirection of present development priorities toward programs of rural development, including efforts to repatriate and resettle unemployed urban migrants; and a major effort on a regional basis to establish indigenous capital goods industries capable of designing and developing labor-intensive technologies for both agriculture and industry. Finally, some program for controlling excessive population growth is necessary even though this is unlikely to be welcomed by all African governments at the present time.

[Extracted from "Income Expectations, Rural-Urban Migration, and Employment in Africa," International Labor Review. Geneva: International Labour Office, Vol. 104, No. 5, November 1971, pp. 387-401.]

Land Tenure and the Rural Exodus in Latin America

R. Paul Shaw

[The prevalence of very large landholdings, when these are inefficiently exploited and detrimental to the economic opportunities of smallholders and farm workers, is likely to increase rural emigration. Analysis of data by province in Chile and Peru, and some international comparisons, support this hypothesis.]

This paper summarizes results of an empirical test of a model which seeks to identify the influence of land tenure on rural emigration in Latin America. Briefly, the model applies to Latin American economies with high rates of rural natural increase, a large proportion of the rural-agricultural population in the minifundio and/or landless employee class, and a large share of the agricultural land held by latifundistas. Minifundios are defined as small farms of 0-5 hectares, and latifundios are large properties of 500 hectares or more.

In the model, the influence of the highly unequal land tenure system in Latin America is represented by four assumptions: (1) A number of forces are operating to keep land, capital, technology, and quality of labor on minifundios relatively constant at low levels of production. (2) Neither land nor labor is being used with economic efficiency on a large proportion of the latifundios. (3) Tenant farming arrangements are not likely to expand tenant or landless working family income possibilities much beyond subsistence levels, due to insecurity of latifundio-controlled tenure arrangements and uncertainty with regard to income. (4) We assume that an individual will be motivated primarily on economic grounds to migrate to a place of residence offering greater economic opportunity if he is confronted with an inability to meet subsistence requirements.

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Empirical studies suggest that: inadequate credit and highly exploitative pricing and marketing arrangements impede possibilities of higher incomes on minifundios; the landless employee class is faced with conditions of surplus labor, unstable land tenure rights, and a general lack of nonagricultural employment possibilities; and the latifundista typically operates below a profit-maximizing position on his production possibility curve, seldom farms land intensively, exploits resident employees and occasional labor, reinvests very small proportions of farm profits, and is, very often, an absentee landlord. These tendencies are reflected in the model to be described, and the role of high and increasing rates of population increase is also incorporated into the model.

Testable Relations

To test the model, empirical measures interrelate the effects of rural population growth with aspects of the structure of the land tenure system. These measures are correlated with estimates of provincial rural male labor-force emigration for populations consisting largely of rural-agricultural households. The key predictor variable is termed an "index of population pressure and agricultural inopportunity." It is represented as both a stock and a flow of labor demands on the land defined as follows. The stock index of population pressure and agricultural inopportunity is:

$$\frac{P_t - f(L_o + L_w + F_o)}{T_A - L_A}$$

The flow index of population pressure and agricultural inopportunity is:

$$\frac{[P_t (1 + r)^n - P_t] - [f(L_o + L_w + F_o)^t (1 + r)^n - f(L_o + L_w + F_o)^t]}{T_A - L_A}$$

P_t = provincial rural-agricultural population at time t; f = average rural family size of each province at time t; L_o = latifundio owners in each province; L_w = latifundio full-time employees and secure tenants in each province; F_o = owners of intermediate-sized farms in each province, that is, 5-500 hectares; r = provincial rate of rural natural increase from time t to t + n; n = years from time t to t + n; T_A = total provincial arable agricultural land (i. e. total nonsterile land minus natural pasture and forested land); and L_A = provincial arable agricultural land held by latifundistas.

In the stock index, P_t represents the total rural provincial population dependent on the land at time t. From P_t, we substract an estimate of all workers and their dependents, $f(L_o + L_w + F_o)$, who we expect would not be confronted by situations of economic stress. The numerator then, as a "population at risk," corresponds roughly with

working and dependent members of the minifundio and landless employee class, the latter comprising farm workers who do not have a secure position on the larger farms.

As a gauge of agricultural opportunities available to the minifundio and landless employee class, we subtract provincial arable land held by latifundistas, L_A, from total provincial arable land, T_A. Exclusion of L_A from total arable land is expected to yield a closer approximation of the range of agricultural income-producing possibilities open to minifundio workers and landless employees because latifundio land is typically farmed extensively and large tracts of this land lie idle. On the other hand, where the latifundista has either created employment for landless employees or provided alternative sources of income for minifundio workers, this has been taken into consideration in the numerator of the index (i. e., $L_w f$).

Arable land available to the majority of the rural population, $T_A - L_A$, includes both land owned and operated by minifundio farm families and intermediate-size farms. The latter has been included given the argument in this model that owners of intermediate-size farms operate on or close to the frontiers of their production possibility curves. Consequently, they are expected to utilize more labor-intensive technology (than on latifundios), to employ more substantial proportions of both full- and part-time labor and to leave little of their land idle.

In the flow index, $P_t(1 + r)^n$ represents the total rural provincial population dependent on the land at time t increasing by the provincial rates of rural natural increase in effect from time t to t + n. By subtracting P_t from $P_t(1 + r)^n$, population growth in the absence of migration is estimated. This step serves to incorporate differential rates of population growth between "sending areas" (and therefore differentials in total living-level requirements). At the same time, by applying the same provincial growth rate to the component $f(L_o + L_w + F_o)$, we arrive at a flow estimate for this population subgroup in the same manner.

The central hypothesis tested in this study is: As the stock or flow index of population pressure and agricultural inopportunity increases, the incidence of rural emigration will increase. If, in fact, the system of land tenure is playing a major role in influencing situations of economic stress and consequently rural emigration, variations in this index should account for the majority of the variation in the rural emigration rates. Three variations of this major hypothesis are also evaluated. Each relates to a more direct measure of the structure of land tenure. That is, the larger the latifundio share of agricultural land, the larger the minifundio share of all farms, or the larger the landless employee class, the greater the incidence of provincial rural emigration is hypothesized to be.

A number of additional hypotheses have also been tested. For example, the influences of provincial urban-rural wages, literacy, and

amenity differentials are considered. These variables have been included largely for evaluating the predictive ability of the "index of population pressure and agricultural inopportunity," in contrast to other surrogates of social and economic well-being. Exemplary hypotheses are: the greater the urban-rural wage differential, and the greater the urban-rural housing quality and quantity differential, the greater the incidence of provincial rural emigration. Also evaluated is the hypothesis that the greater the extent of provincial rural illiteracy, the smaller the incidence of rural emigration.

Empirical Results

The burden of the statistical analysis relies on cross-sectional data at the rural provincial level for three Latin American countries: Chile, 1952-60; Peru, 1940-61; and Costa Rica, 1950-63. As migration flows demonstrate unique characteristics in each country, analyses have been performed separately. Detailed results for Chile appear in table 1, and some summary figures for Chile and Peru in table 2. [The Costa Rica results are omitted here as they are based on a relatively elaborate graphic analysis. They also provide support for the model.]

Generally speaking, these results support the hypotheses described. In table 1, the strongest single-variable correlations with provincial emigration rates in Chile are found for the two indexes of population pressure on land (variables C_{5a} and C_{5b}). Both are significant at the .01 level; it may be noted that the flow index produces a somewhat higher correlation than the stock index, indicating that differences in local rates of increase in the "Population at risk" do have an influence on migration. Next in levels of correlation and statistical significance are the variables relating to the structure of agriculture. Clearly the percentages of land in latifundia (variable C_2) are important, as are the percentages of the workforce on minifundia weighted by population growth rates (variable C_3). Percentages of land in minifundia (C_1) are positively related also, but not more significantly than some other variables. The measures relating to income levels, education, amenities and transport facilities appear with the expected signs, but none are as highly or significantly correlated with provincial emigration rates as are the population pressure indexes and the leading structural variables.

In the multiple regressions [not shown here] the stock or flow indexes dominated every regression. For Chile, no other variables were significant when one of these indexes was included. For Peru, results were generally similar to those described for Chile except that the "best-fit" equation for Peru was one in which the percentage of urban population in the provinces (variable C_{11}) was of marginal significance along with the much more strongly weighted stock index (C_{5a}).

TABLE 1

Chile: Simple Correlation Coefficients for 13 Independent Variables with Rural Emigration Rates During 1952-60 (Provincial Rural Male Labor-Force Emigrants Per 100 of the Provincial Rural Male Labor Force)

Independent Variables	Simple R
Structure of agriculture:	
C_1 = % provincial farm holdings having less than 5 hectares (minifundios), 1955	.52*
C_2 = % provincial agricultural land held by farms greater than 500 hectares (latifundios), 1955	.67**
C_3 = % provincial agricultural labor force on farms less than 5 hectares weighted by average provincial population growth rates, 1952-60	.77**
C_4 = Average % provincial labor force that are agricultural employees and productive workers, 1952-60	.34
Indexes of population pressure on land:	
C_{5a} = stock index, 1952	.84**
C_{5b} = flow index, 1952-60	.88**
Income effects:	
C_6 = average provincial agricultural wage, 1952-60	−.51*
C_7 = % change in provincial agricultural wage, 1952-60	.00
C_8 = average provincial urban wage index as a multiple of average provincial rural wage index, 1960	.06
Education:	
C_9 = average % provincial rural male population illiterate, 1952-60	−.36
Differential amenities:	
C_{10}= average % provincial urban population literate as a multiple of average % provincial rural population literate, 1952-60	−.29
C_{11}= average % provincial population urban, 1952-60	.31
Transportation:	
C_{12}= no. cars, trucks, and buses per 1,000 provincial population, 1960	.49*

*Significant at .05 level.

**Significant at .01 level.

In defense of the stock and flow indexes over simpler measures in accounting for rural emigration, see the results in table 2. Index 4 is a typical population-pressure measure used in demographic studies. It does not address production possibilities, i. e. arable agricultural land actually available for cultivation. Replacing the denominator in index 4 with T_A (provincial arable land) improves the predictive import of index 3. In support of the argument that latifundismo seriously restricts production possibilities of the rural population in general, index 2 (subtracting L_A) accounts for more of the variation in the migration measure. The results for index 2 as against index 3, then, support the hypothesis that latifundism increases emigration. Finally, the higher correlations that result from subtracting the component $f(L_o + L_w + F_o)$ in index 1 tend to support the assumption that this rural population subgroup is not experiencing the same income-producing problems as the population at large and therefore should be excluded from the measure of agricultural inopportunity. The statistical results for Peru correspond with those for Chile, although the R^2 (adj.) is on the order of 20 percent less. Generally, the results shown in table 2 are similar for the flow index for both countries. Through inclusion of the population growth rates, the flow index enabled from 2 to 5 percent more predictive capacity for Chile, and for 4 to 8 percent more predictive capacity for Peru, than use of the stock index.

TABLE 2

Simple Linear Regression Results for Chilean and Peruvian Rural Provincial Emigration and Variations on Stock Index of Population Pressure and Agricultural Inopportunity

Index	Population Pressure Measure	R^2 (adj.) for each Index and Rates of Provincial Rural Emigration: Chile	Peru
1.	$[P_t - f(L_o + L_w + F_o)] / (T_A - L_A)$	.70	.50*
2.	$P_t / (T_A - L_A)$	.65	.44
3.	P_t / T_A	.55	.04
4.	P_t/ (total nonsterile agricultural land including pasture and forests)	.13	.00

*For index 1 and the case of Peru, inadequate data prevent an estimate of L_w. On the basis of the present assumptions and model, we would expect a higher R^2 value had this component been included.

International Comparisons

As a final reflection on the relevance of the model for understanding rural emigration in Latin America, consider the rural emigration experience of 16 Latin American economies in relation to the structure of their land tenure system (table 3). Again, we find a strong indication of the significance of the distribution of land ownership as an important influence. As table 3 indicates, the average yearly rate of net rural emigration for five countries with less than 50 percent of their farms held as minifundios and less than 50 percent of the land held by latifundistas is 0.56. In contrast, systematic increases in either the proportion of minifundio farms or the proportion of the land held by latifundistas are accompanied by a higher rate of rural emigration. It is also interesting to find that, as in the provincial analyses for Chile, Peru, and Costa Rica, the rates of rural emigration in the 16 countries is slightly higher when the proportion of land held by latifundistas is higher than when the proportion of farms held as minifundios is higher (see note to table 3). One possibility is that minifundio ownership implies ties to agriculture (possibly an inertia effect). On the other hand, large proportions of land held by latifundistas implies not only a host of uneconomical and exploitative conditions noted previously, but possibly a greater awareness of relative deprivation on the part of the minifundio and landless employee class, especially as their general level of education increases.

TABLE 3

Average Yearly Rates of Rural Emigration for 16 Latin American Countries Classified by Proportion of Farms Less than 5 Hectares and Proportion of Land on Farms Exceeding 500 Hectares, 1950-60.

Countries with 0% - 50% Land On Farms Exceeding 500 Hectares (A)		Countries with 50% - 100% Land On Farms Exceeding 500 Hectares (B)	
0% - 50% Farms Less Than 5 Hectares (a^1)	50% - 100% Farms Less Than 5 Hectares (a^2)	0% - 50% Farms Less Than 5 Hectares (b^1)	50% - 100% Farms Less Than 5 Hectares (b^2)
Rate of rural Emigration... 0.56	1.48	1.60	2.33
N.....5	5	3	3

SOURCE — Computed from respective agricultural census of each country, The Statistical Abstract of Latin America (Los Angeles: University of California, Latin American Center, 1965-69), and America en Cifras (Washington, D. C.: Pan American Union, 1965-680.

NOTE — Sum rate for A = 1.02 (N = 10); sum rate for B = 1.96 (N = 6); sum rate for a^1b^1 = 0.95 (N = 8); and sum rate for a^2b^2 = 1.80 (N = 8).

Again, as a contrast to this explanation of rural emigration in Latin America, a simple population density measure is evaluated in table 4. It is clear, however, that considering only absolute levels of population relative to the land base without considering factors influencing the nature of productive activity is of little utility in understanding conditions leading to rural emigration.

TABLE 4

Average Yearly Rates of Rural Emigration for 16 Latin American Countries classified by Density of Rural Population Per Square Kilometer of Arable Land, 1950-60

	0-49	50-99	100-149	150-199	200-249	250-299	300-349	350-399
Rate of rural emigration	2.20	1.90	0.80	1.85	1.65	1.13	0.80	1.60
Number of Countries	1	2	4	2	2	3	1	1

Implications

The principal finding of this inquiry is that land tenure is empirically related to rural emigration in Latin America. This finding bears directly on two important policy and planning concerns: Is the "mechanism" of rural-urban migration in Latin America operating effectively in its allocation of the economy's population and labor force relative to potentially productive resources in the country's rural sector and actual opportunities in the country's urban sector? Are large rural-urban migration flows in Latin America phenonomena which must merely be adjusted for, while the countries involved attempt to cope with increasing rates of urban unemployment and underemployment, urban housing shortages, etc. ? An implication of this study, then, is that land reform, small-farm credit programs, more adequate market mechanisms for minifundio products, and extension programs for members of the minifundio and landless employee class are likely to have benefical side effects such as slowing rural-urban migration and reducing open unemployment in cities and strain on the urban infrastructure.

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Urbanization and Migration in Taiwan

Alden Speare, Jr.

[Internal migration in Taiwan, though predominantly rural-to-urban as in other developing countries, differs in some respects due to effective rural development policies resulting in a greater attractiveness of farming than is usual elsewhere, also to the considerable dispersion of industrial growth into small towns. Thus the rural dwellers have more opportunities, and the urban "pull" is as tenable an explanation of migration as the negative rural "push" hypothesis.]

Between 1920 and 1970, the population of Taiwan grew from 3.7 million to 14.7 million. Most of this increase was due to the natural increase of the Taiwanese. During 1945-50, the Japanese who were living in Taiwan were repatriated to Japan, and Nationalist Chinese moved to Taiwan in the wake of the Communist takeover on the mainland. The influx of the mainland Chinese in the late 1940s did not result in a substantial increase in the total population. The population growth rate of 2.5 percent a year during the 1940s was similar to the growth rates for the two preceding decades; it rose to 3.6 percent in the 1950s and 3.1 percent in the 1960s. The rapid increase of the Taiwanese population has been primarily the result of a high birth rate and a falling death rate. The birth rate fluctuated between 40 and 45 births per 1,000 up to 1960, after which it declined, reaching 27 births per 1,000 in 1970. During the same period, the death rate declined from about 25 deaths per 1,000 in the period 1920-25 to about five per 1,000 in 1970.

In 1920, most of the available land in Taiwan was already in use, and in the following 50 years the total cultivated land increased only from 749,000 hectares to 905,000 hectares. Since few of the new additions

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to the labor force were able to obtain new lands to cultivate, the population growth has resulted in both an increase in the ratio of rural population to land and a shift toward nonagricultural employment. The proportion of the labor force employed in agriculture and fishing declined from 70 percent in 1920 to 35 percent in 1970.

The result has been that the cities have grown considerably faster than the countryside. Between 1920 and 1970 the population of the five major cities increased almost tenfold in comparison with the rest of Taiwan, which increased fourfold. Migration has been greatest to the largest cities. For example, between 1961 and 1966 the average annual net migration rate was 15.9 per 1,000 population for the five largest cities, 12.5 for the other five cities over 100,000 and 4.9 for urban townships between 50,000 and 100,000. Smaller urban townships and rural townships lost population, on the average.

Although we have clearly documented a pattern of migration from rural to urban areas, we cannot yet conclude that the major cause of this migration has been the growing population pressure on the limited land resources in rural areas. While there has been little increase in the amount of cultivated land since 1920, agricultural yield per acre has more than doubled. The more uniform distribution of land that resulted from the 1953 Land-to-the-Tiller Act increased the attractiveness of farming for small farmers. Many of the small farmers, who might otherwise have moved to the city, may have been encouraged to remain on the land. Furthermore, much of the industrial growth occurred outside the largest cities. Approximately 44 percent of all men in Taiwan who were registered as employed in manufacturing lived outside the 10 largest cities in 1965. An alternative to the rural push hypothesis which seems equally tenable is that people from rural areas have been attracted to the cities because they are able to earn higher wages and obtain types of employment which are more enjoyable than farming. To resolve this question, we shall turn to the analysis of the characteristics of migrants.

The Migration Record Sample

Taiwan is one of the few nations to possess a household registration system sufficiently accurate and complete to permit a detailed study of the urbanization process from official records. The Civil Affairs Department collects routinely a random sample of approximately 2 percent of the migration records for persons who registered moves across township boundaries each month. The Civil Affairs Department also obtained a sample of household records for approximately 0.3 percent of the households in Taiwan, irrespective of migration status, in December 1967. Since these two samples were designed to yield comparable data for migrants and the general population, we can compute migration rates for people with specific characteristics

by using the migration data for numerators and the general population data for denominators and applying appropriate weights. Because the samples are large, migration rates can be calculated for detailed subgroups of the population. The analysis reported in the remainder of this paper is based on original tabulations of the migration records for 1967 and 1968 and the household records collected at the end of 1967. These sources provided a total sample of 28, 297 migrants and 41, 276 residents.

The estimates of gross migration in various streams based on tabulations of individual migration records tend to confirm that net migration flows in Taiwan are in the direction of greater urbanization, particularly toward the five largest cities and the small cities and urban towns with populations over 50, 000. However, these net flows account for only a small proportion of the total migration in Taiwan. For instance, the major cities received 245, 200 migrants in 1968 and sent out 185, 000, while the small cities and urban towns received 236, 000 migrants and sent out 219, 300. This means that the ratio of net in-migration to total in-migration was about one in four for the major cities and one in 14 for the small cities and large urban towns. Since the migration records contain no prior moves, we have no way of identifying return migrants. If most migrants moving from major cities to rural towns were returning to their previous homes, then approximately half of all migrants from rural towns to the city return to the rural towns. This figure may well be an underestimate, since many persons who return to their place of origin within a year of their original move fail to register either move and are not counted in the migration register.

Characteristics of Migrants in Particular Streams

The migration records provide data on the birth date, education, occupation, and domicile for each migrant. The term "domicile" refers to the place of origin of a person's family. It provides a means of distinguishing native Taiwanese from the Chinese who moved from the mainland of China since World War II and their descendants.

As in most of the world, internal migration in Taiwan is highly age selective with the highest rates of migration occurring between the ages of 15 and 44. Taiwan, however, has one peculiarity due to the fact that the mainlanders have an age distribution which is skewed toward the older ages. Since mainlanders tend to be more mobile than native Taiwanese, their inclusion leads to higher mobility rates for the older age groups than one observes elsewhere. When the two groups are separated the migration rates for Taiwanese show the normal relationship to age (see table 1). With the exception of ages 30-44, when male migration rates exceed female rates by 29 percent, there is little difference

between migration rates for males and females among Taiwanese. The similarity of rates in the 15-29 age range when many of the migrants are single indicates that both sexes are responding equally to the changing economic conditions. While males are differentially attracted to transportation, construction, and heavy industry, some of the newer export industries attract more women than men. For example, the Kaohsiung export processing zone, established in 1965, was employing 15,000 workers by the end of 1967, 87 percent of whom were women.

Mainlanders differ considerably from Taiwanese in the variation of migration rates with age and sex. The highest migration among mainlanders is for males aged 30-44. The migration rate for this group is nearly double that for mainlander females and about two and a half times greater than that for Taiwanese males in the same age group. The same is true of the migration rate for mainlander males aged 45-59. The explanation for these differences is related to the fact that many of the mainlander males in these two age groups are single men who have retired from the army, having moved to Taiwan in 1949-50 under Chiang Kai-Shek. With no family and no previous civilian residence, these men tend to be highly mobile. Because a large part of the variation in migration rates of the mainlanders is related to unique historical factors rather than more general social and economic factors, we shall confine the remainder of our analysis to the native Taiwanese.

Table 1: Migration Rates By Age And Sex For Taiwanese And Mainlanders (Rates per 1,000 in 1967-68)

	Taiwanese			Mainlanders		
Age Group	Males	Females	Male Rate/ Female Rate	Males	Females	Male Rate/ Female Rate
0-14	41.8	40.7	1.03	83.0	85.5	0.97
15-29	78.1	75.0	1.04	69.8	116.7	0.60
30-44	58.6	46.4	1.26	151.6	73.1	2.08
45-59	35.6	33.2	1.07	100.5	57.9	1.74
60+	21.2	22.2	0.96	76.5	58.5	1.31
Total	52.2	48.5	1.08	101.2	89.8	1.13

In general, migrants in Taiwan tend to be drawn disproportionately from the better educated. Both male and female migration was selective of the better educated in seven of the nine streams between cities, urban towns and rural towns. In all seven of these streams those who had completed senior school had the highest migration rate, and those who had not completed primary school had the lowest rate. In most of

these streams, there was very little difference between the rates for primary school graduates and junior school graduates.

This selectivity was greatest in the three streams toward greater urbanization (rural towns to cities, urban towns to cities, and rural towns to urban towns). The percentage of migrants in each stream who are junior graduates or higher show a regular progression with respect to both place of origin and place of destination. Migrants from cities are better educated than migrants from urban towns, who are, in turn, better educated than migrants from rural towns. Similarly, among migrants leaving a particular point, those who go to the cities have the most education; those who go to the rural towns have the least education.

Although migrants tend to be better educated than the residents at their place of origin, they are not necessarily better educated than the residents at the place of destination. In the streams toward greater urbanization, migrants tend to be intermediate in education between the residents at the place of origin and those at the place of destination. This is true for females in the streams from urban towns to cities, rural towns to cities, and rural towns to urban towns. It is also true for males in the rural-towns-to-cities stream. However, in the streams from urban towns to cities and from rural to urban towns, male migrants are slightly more likely to be junior graduates than males at the destination.

Migrants who move in the direction of lesser urbanization have more education than the residents at the place to which they move. In fact, the proportion of migrants who are junior graduates differs little between the major flow and the reverse flow between two types of places. For example, 32.8 percent of the male migrants from rural towns to cities are junior graduates, and 32.5 percent of the male migrants from cities to rural towns are junior graduates. This means that if we assume that a large proportion of the persons in the reverse flows are return migrants, the probability of a migrant returning must depend very little on his education.

It is hard to reconcile the lack of educational selectivity in the return streams with the high degree of selectivity in the major streams. If educational selectivity in the streams toward greater urbanization is due to greater opportunities of finding satisfactory employment for the better educated, we would expect the return streams to be disproportionately drawn from the poorly educated who would have less success in finding satisfactory employment. However, education may have little effect on one's chances of obtaining satisfactory employment in the city since what one defines as satisfactory may vary with one's education. Taiwan has a high proportion of junior and senior high school graduates relative to its level of development, and it may be harder for them to find jobs commensurate with their education than it is for someone with less education. Thus, while many highly educated persons may be motivated to leave rural areas because there is little opportunity for them to find work which utilizes

their skills there, they may be no more successful in finding such work in the cities than the poorly educated migrant who seek unskilled employment.

Another explanation is that many migrants improve their education in the city and some come primarily to gain further schooling with the intention of returning. If we could first separate out those migrants who initially intended to return and then compare the current educational level of the other return migrants with those who stayed in the city, we might well find that those who returned had less education than those who stayed.

Finally, despite the similarity in average educational attainment between migrants in the primary and return migration streams between rural townships and cities, there is still a selective loss of the more educated persons by the rural areas because more migrants leave than return. Thus we may still speak of the net migration between rural townships and cities as selective of the better educated.

Taichung Migration Survey

This survey consisted of intensive interviews with two samples: one a sample of 321 Taiwanese men aged 23-42 who had registered a move to Taichung City from one of the four surrounding counties in 1966-67; the other was a sample of comparable men living in rural and urban towns within these four counties. The survey results indicate that migrants are positively selected with respect to education. Migrants were also less likely than nonmigrants to have been employed as a farmer or to have lived on a farm just prior to moving. However, there was little difference between migrants and nonmigrants in the proportion who had ever lived on a farm. This indicates that for many migrants the move to the city was the last step in a series of moves away from farming.

Table 2: Selected Characteristics Of Migrants And Nonmigrants
(Percentages of sample)

	Migrants (before move)	Nonmigrants
Graduated from junior school (ninth grade)	38.0	20.5
Employed as salaried professionals, managers, or clerks	20.6	8.9
Employed in production or construction	17.8	11.6
Employed as farmers or farm laborers	18.7	43.5
Not employed	4.7	3.5
Living in farm families	38.3	56.8
Those living in farm families whose imputed farm income exceeds $900 per year*	33.3	19.1
Ever lived on a farm	82.7	83.9
Numbers in sample	321	370

*Base of percentage is number living in farm families.

Twenty-one percent of the migrants said they had been employed as professionals, managers, or clerks compared with 9 percent of the nonmigrants. Many of the white-collar workers were government employees; the majority of these worked for local government or state enterprises. Employment in the Chinese civil service has traditionally involved a considerable amount of geographical mobility. The old principle was to rotate the higher officials to keep them from developing local ties which might mitigate against their loyalty to the central government. We have not ascertained the extent to which this principle is still adhered to by the Nationalist Chinese, although the fact that a large percentage of the moves of government employees were job transfers requested by the government implies that this principle may still be followed.

Migrants from farms tended to be selected more from the larger farms than the smaller farms. We have standardized the data on family landholdings by converting them into imputed monthly income based on the average total income (including income in kind) for different types of land obtained from agricultural surveys. Among those who had lived on a farm, more migrants than nonmigrants lived on farms with imputed yearly incomes of $900 or more. The greater migration from larger farms is a function of two factors. First, members of families with larger holdings have a greater opportunity to obtain advanced education. The data show that they do in fact have better education, and that when educational level is controlled there is little difference in the migration rates by farm size. Second, members of poorer families who do not move to a large city have other rural alternatives to work on the family farm. They can work as agricultural laborers; they can also take up nonagricultural employment in the village or commute to one of the nearby factories.

Summary and Conclusions

Since World War II, the cities of Taiwan have grown at an average rate of close to 5 percent per year. The rate of net out-migration from all areas was found to be the highest in areas where a high percentage of the males were employed in agriculture. With the exception of a relatively small movement to the east coast of Taiwan where some new land has been put to cultivation, recent net migration in Taiwan can be explained as almost entirely a move from agricultural areas to cities and large urban towns (over 50,000). But even though virtually all available land in Taiwan has been intensely cultivated for some time and the rural population has been growing rapidly during this period, these facts do not necessarily imply that the rural-urban movement has been primarily due to a rural "push." While the rural population has been growing, the population growth has been more than offset by increases in agricultural yield resulting from the introduction of new seed, fertilizer, and improved irrigation. Land reform, by dividing the land more equitably, may have made farming more attractive for many who otherwise would have left the rural areas. Furthermore, some of the industrialization in Taiwan has permeated the countryside, and there has been increased opportunity for

nonagricultural employment both within rural areas and within commuting range of these areas.

With a few exceptions, therefore, rural-to-urban migration in Taiwan can be viewed as a rational response to changing economic conditions. The growing rural population has adjusted to the pressure of population on limited resources by sending to the major cities those members of the rural population who are best qualified for urban employment. The migrants have been drawn disproportionately from the young adults, from the more highly educated, from those working most recently in nonagricultural employment, and from the larger farms. The cities have not had to assimilate large numbers of poor, ill-prepared rural residents leaving the countryside because of population pressure and limited opportunities for work. Instead, those with less education and members of large families on the smaller farms have tended to seek other employment nearby, either through seasonal employment as an agricultural laborer or in local nonagricultural employment or by daily commuting to nonagricultural employment in a smaller urban place.

Although the major net flow of migration was from rural areas to the major cities, this net flow was only a small part of the total internal migration in Taiwan. On the average, for every four migrants who entered the major cities there were three migrants who left these cities, many of them probably returning to their original places of residence. The finding that these "return migrants" were approximately equal to the primary-stream migrants in education could not be explained, and there is a need for more detailed studies of return migration and its relationship to economic development.

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Mixtec Migrants in Mexico City

Carlos L. Orellana S.

[This article examines the formation of a village association among a group of Mixtec migrants from the village of San Bartolo Soyaltepec living in Mexico City. The village association is of critical importance in the adaptation to urbanization, which also involves changes in the social organization of the rural community.]

The Mixtec Indians occupy a large area in southern Mexico in northern and western Oaxaca and in adjoining portions of the states of Guerrero and Puebla. The Pan American Highway between Mexico City and Oaxaca is only four hours walking distance south of Soyaltepec, a municipality in the Mixtec area. Soyaltepec itself, however, remains quite inaccessible as no roads enter it. This relative isolation has contributed to the maintenance of a traditional cultural configuration in the social structure of the municipality.

The municipality of Soyaltepec is composed of four communities organized according to the municipal form of government. The formal seat of power for the municipality is located in the village of San Bartolo. The maintenance of the civil government depends, to a large extent, on the system of communal participation, referred to as tequio. All members of the community are eligible and required to hold office whenever called upon by the civil authorities. Once called upon, there is no way to refuse. This system provides an institutionalized cultural basis for maintaining an active political community among Mixtecs.

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TABLE 1. Residence of Municipal Population of Soyaltepec in 1970

Villages	Total Community Populations (1970)	Municipal Residents		Migrants (Absentees)		
		No.	%	Total	In Mexico City	In Veracruz
San Bartolo	523	247	47.0	276	203	73
La Union	497	403	81.0	94	53	41
Tejocotal	272	182	67.0	90	57	33
Rio Verde	473	235	49.6	238	134	104
Totals	1,765	1,067	60.0	698	447	251

Source: The San Bartolo Soyaltepec census reports for 1970.

The population of the municipality is given as 1,756 individuals. Forty percent of these people, however, are reported as being resident outside of the municipality. The municipal census records indicate that the principal migration destinations are Veracruz and Mexico City. A sample of 57 of the migrants to Mexico City were interviewed to obtain data on migration and residence, employment, political participation and community interaction.

The Union Vecinal

The Union Vecinal was formed by the migrants in Mexico City in order to facilitate adaptation to the city in terms of employment, housing, and community solidarity. The legitimacy which the Union has been able to achieve from the community is by and large a function of its ability to carry out major construction projects in the village and to provide employment for the migrants in the city.

It has established this economic base in the city by providing access to employment through one of the more important labor unions of Mexico, The Confederación de Trabajadores Mexicanos (CTM). The CTM provides employment within a protected sector and thereby prevents the migrants from falling into what is commonly referred to as the "bazaar sector" of the economy. The jobs provided by the CTM range from unskilled labor to that of factory foreman. Fifty-one migrants (90% of the sample) have at some time in their urban experiences been members in this labor union. Five of these constitute the original core of the Union Vecinal who obtained their first

jobs with each other's assistance in 1940. The remaining 46 migrants referred to the Union for employment. Twenty-two of this latter group joined the CTM immediately upon arrival in the city. The other 24 joined after having tried their luck at only one other job which proved to be noncomparable to a CTM job. Only six migrants in the sample had never referred to the Union for employment: two of these became printers' apprentices, three obtained membership in other labor unions, and the sixth became incapacitated in an accident shortly after arrival.

The Union Vecinal strives to keep the channels of employment open for all migrants by encouraging participation in the CTM. Participation in this union is required only of those migrants who are working members. In addition to being a rank and file member, there are three positions in the CTM which a migrant may hold. The list below indicates the frequency of participation among the migrants employed in the CTM at the time of this study; fourteen migrants were employed elsewhere.

Rank and File Members	27
Representatives	9
Delegates	5
Officials	2
	43

The two officials are in charge of numerous functions within the CTM, many unrelated to the Union Vecinal. As officials of a specific section within the CTM, however, most of the Soyaltepec migrants are within their jurisdiction. The five delegates are liaisons between the workers and the CTM. The nine representatives are active only during contract bargaining and other special occasions. Rank and file members are required only to pay dues and vote in CTM and national elections.

The evidence of employment stability and upward mobility among the migrants from Soyaltepec attests to the importance of the labor union employment provided by the Union Vecinal. Twenty-two migrants have experienced some upward mobility either within the ranks of their CTM employment or as a consequence of it, and two migrants have become "professionals." For the large body of migrants the CTM has provided job stability. Excluding the incapacitated migrant, only four individuals were unemployed or holding marginal jobs at the time of interview. Two of these individuals had been fired for drinking on the job and two were fired from their CTM jobs for not cooperating in a tequio with the Union Vecinal.

The marked increase in the frequency of migrants arriving in Mexico City after the founding of the Union Vecinal in 1940 is indicated in Table 2.

Not all the migrants, however, came directly from the village to Mexico City. In the earlier periods of migration from Soyaltepec, the port city of Veracruz was the favored point of destination because a group of migrants had established a Union Vecinal in Veracruz. With the growth of the Union in Mexico City, a greater number of villages began to choose Mexico City as a destination at the time of migration. Table 2 indicates this change as well as the fact that 25 migrants who originally went to Veracruz later remigrated to Mexico City.

TABLE 2. CHANGING PATTERNS OF MIGRATION (numbers of migrants in sample)

	Rate of Migration from Village	Initial Point of Destination: Veracruz	Initial Point of Destination: Mexico City	Arrivals in Mexico City
1921-1930	4	4	0	1
1931-1940	7	5	2	7
1941-1950	10	4	6	7
1951-1960	13	7	6	13
1961-1970	23	5	18	29
Totals	57	25 (stage migration)	32 (direct migration)	57

For the migrants from Soyaltepec, due to the particular type of employment opportunity available through the Union Vecinal in Mexico City, the migration process selects for age. The youngest reported age at which an individual obtained membership in the CTM was 16. Only one individual who arrived in Mexico City before the age of 16 obtained a job comparable to a CTM job. All the others had many jobs, low job quality, and long periods of unemployment; that is to say, high levels of marginality. Prior to 1950, 66% of the migrants leaving the village were 15 years or younger, in contrast to only 45% in the period after 1950. Seventy percent of the migrants in the 13-15 age category chose Veracruz over Mexico City as their initial point of destination, while 72% of those 16 and older selected Mexico City as a first choice.

Residence patterns. One of the more difficult projects the Union Vecinal has set out to accomplish is that of providing the migrants with a territorial base for community solidarity. In 1940 when the Union was established, most of the migrants were living within a few doors of each other in Colonia de los Doctores in what is now

the central district area of Mexico City. At that time, however, the Colonia de los Doctores was a sparsely populated residential neighborhood on the southern fringe of Mexico City's metropolitan area. The Union, therefore, was able to maintain an informal structure within a neighborhood environment. The urban expansion of Mexico City and the growth of the migrant community from Soyaltepec in the city had the effect of undermining the territorial basis of the Union Vecinal because it forced the newer migrants to seek housing elsewhere in the city. Many of the migrants began to settle in Colonia Anahuac on the northern fringe of the city close to the developing industrial zone.

In an effort to preserve the social and territorial basis of the community, the Council of the Union decided to unify the migrants and resettle them in an abandoned area on the southern fringes of the city referred to as Ajusco. In 1948, proclaiming themselves to be colonizers, several migrants settled on the lava beds of Ajusco and began to build their own houses. The government referred to them as squatters and attempted several times to evict these settlers from their homes. The government was unsuccessful; and the legal problems and the numerous incidents of violence which ensued had the effect of creating a politically conscious and able leadership core among the migrant community. Eventually, only about ten families from the community remained in Ajusco. Most of the migrants continued to settle in Colonia Anahuac until 1960 when the urban expansion began to create a pressure on housing in that area very much as it had done previously in Colonia de los Doctores. During the 1960s, when almost half of the sample reached Mexico City, the new arrivals settled in a variety of areas. By 1970 the settlement pattern of the migrants in the city had changed drastically: only those migrants who were clustered in 1960 continued to remain clustered, and the Colonia de los Doctores had been altogether abandoned.

Political activities. While the resettlement of migrants did not succeed in preserving the physical unity of the migrant community in the city, it did have the effect of politicizing the Union Vecinal and transforming it from an informal neighborhood group to that of a formally structured association. In 1956, armed with a politically able leadership, the Union Vecinal decided to become actively involved with the home village by appointing its first municipal president to the village civil government. The influence of the council of the Union on the village political system became evident in the following years.

The administrative hierarchical organization of the Union Vecinal differs only slightly from that of the village civil government. In addition to being a member, there are two levels of formal participation. At the highest level there is the Council which is formed by the Representantes Permanentes. At the second level are officers appointed by the Council for one-year terms, consisting of a president, a secretary, a treasurer, a legal advisor, and several vocales named to carry out committee work on projects that may arise in the course of the

year. Participation in the Union is maintained through enforcement of the traditional tequio system of community obligation which is required from all migrants. Every individual is expected to pay contributions and to serve as an officer when called upon to direct a community project. Only four migrants in the sample interviewed had never cooperated with the Union Vecinal.

Ten individuals had participated in the Soyaltepec village civil hierarchy before migration, and six continued participating in the Union Vecinal as officers. One individual participated in the village civil hierarchy both before migration and after. Seven migrants returned to participate in the village civil hierarchy although they never participated before migration. Further examination revealed that three pre-1950 migrants held the highest officer position of municipal president at various times since 1950; all of these returned to Mexico City after their turn of office.

In 1956 the Union Vecinal succeeded in a political maneuver and took control of the village civil government by appointing one of its own council members to the position of municipal president. In 1962 the municipal government, with the aid of the Union, received a settlement from a foreign company which had been carrying out mining explorations in the municipality. Several construction projects were initiated, among these the building of several schoolhouses, and each village received sufficient concrete to lay out basketball courts. At this time the government house was built in San Bartolo, a telephone was installed, and a community development project was initiated by the Union Vecinal in conjunction with the residents of the municipality.

By 1963 the project had produced a considerable amount of factionalism in the community, and the authority of the Union Vecinal was seriously challenged. The principal complaint of the villagers was that the Union had not taken their suggestions for projects into consideration. In this year the Union was sufficiently factionalized so that it could not decide on a new municipal president, and the villagers regained control of the municipal government. For the next six years the Union Vecinal became occupied with rebuilding a basis of community support among the migrants in the city. By 1969 the Union had collected sufficient funds from the urban migrants to carry out another project in the village. The Union then succeeded in overriding the villagers' candidate for municipal president and appointed one of the councilors from its own ranks for a three-year period. By 1970 it had managed to regain control of the municipal government.

The growing role of the union in village politics has led to the creation of an associational council in which the village council and the

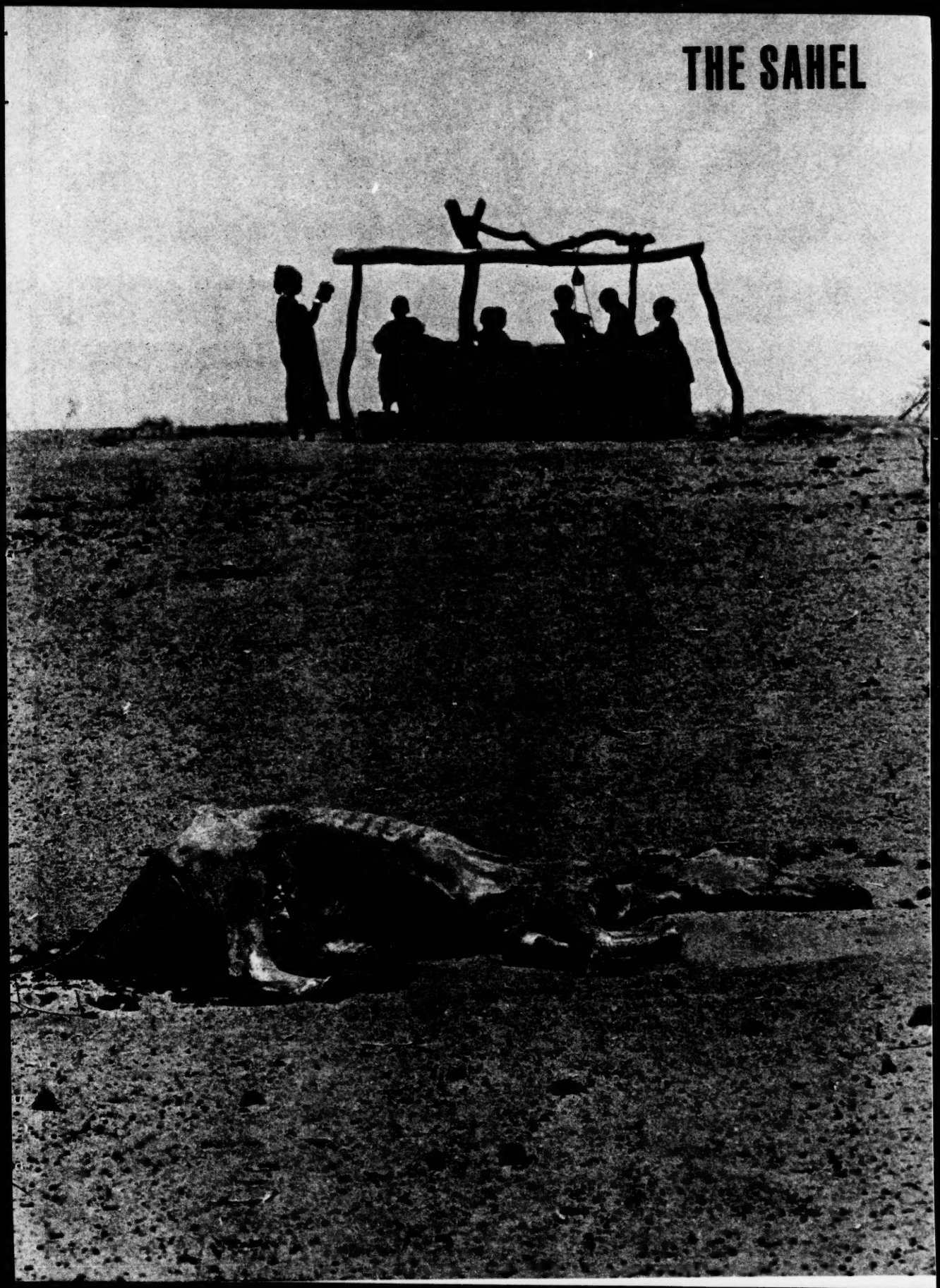
council of the Union each have equal representation and, theoretically, equal decision-making power in community affairs. This arrangement for joint leadership is the most recent organizational innovation resulting from the adaptation of this society to urbanization.

Conclusion

The existence of a village association in Mexico City comparable to the better known regional associations in Lima provides further evidence that urbanization is a complex process in which societies with similar cultural-historical traditions may develop similar adaptive strategies to urbanization. It is possible to indicate some conditions which appear to be prerequisite for the emergence of a village association among migrants to a big-city environment. Village associations grow up among rural Indian migrants coming from villages with a strong tradition of communal activity systems. The fundamental characteristic which promotes the successful adaptation of Indian communal systems to urbanization is the capacity of the group to actualize itself politically through a formalized village association. Political actualization is facilitated in turn by the group's capacity to create an economic base in the city. The formation of such a village association will not take place separately from the social and political system in the rural village.

[Extracted from "Mixtec Migrants in Mexico City: A Cast Study of Urbanization," Human Organization, Vol. 32, No. 3, Fall 1973, pp. 273-83. Copyright©, Society for Applied Anthropology.]

THE SAHEL



DROUGHT SCENE IN SENEGAL
[PHOTO: AGENCY FOR INTERNATIONAL DEVELOPMENT]

The Drought in West Africa

Victor D. DuBois

[During 1968-73 the inland countries of West Africa experienced an extremely severe drought, the worst in this century. The major factors contributing to the disruption of life in these countries in this period, and the consequences of the drought, are described.]

The Sahelian-Sudanic area of Africa is a vast, semi-arid bioclimatic region extending southward from the southern rim of the Sahara Desert roughly to the 14th degree north latitude, and eastward from Senegal on the Atlantic Ocean to Ethiopia on the Red Sea. The Sahelian zone, or "Sahel," is that part of the Sahelian-Sudanic area that lies immediately south of the Sahara. The rainfall in this zone averages less than 25 inches per year; the vegetation is semi-xerophytic (drought resistant). It is distinct from the Sudanic zone, a term properly applied to the area farther south, across West, Central, and East Africa where the annual rainfall is between 25 and 60 inches a year, and where vegetation can vary from tall grass and scattered trees to steppe and brush savannah. The term Sahel will be used in this article to refer to the six nations — Senegal, Mauritania, Mali, Niger, Upper Volta, and Chad — that have been most seriously affected by the drought.

Historically and culturally, the Sahel was once one of the most important regions in Africa. The Sahel enjoyed its greatest renown from the eleventh to the seventeenth centuries, when its major towns — Gao, Djenne, Timbuktu, to mention but three — rose in importance not only as entrepots for the numerous caravans that wound their way across the Sahara, but as the centers of large, powerful and well-developed empires which enjoyed a high degree of civil administration, economic wealth, and cultural attainment. In

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the eighteenth century, due to such factors as the spreading of the slave trade and internecine tribal wars, the Sahel entered a period of decline. Much of West and Equatorial Africa was conquered by the French and the British at the end of the nineteenth century.

Today, the countries that comprise the Sahel are, for the most part, extremely poor and underdelveloped. Their known natural resources are few and are often too remote or costly to be exploited. The vast majority of their peoples are either nomadic pastoralists or sedentary subsistence farmers who manage a precarious existence from an environment which is by and large harsh and unyielding. The average life span is 40 years, and the literacy rate has not risen much beyond 10 percent.

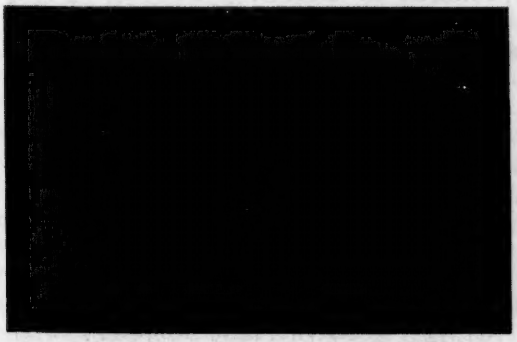
Evolution of the Recent Crisis

Since 1968 this area has suffered from a progressive decrease in rainfall. It was not until 1972, however, that the lack of rain became so acute as to raise the specter of widespread famine. In September 1972, government authorities in many hinterland regions reported the southward movement of unusually large numbers of nomads who normally inhabit the northern areas of their countries. There had always been a sizable migration of nomads with their herds of cattle, sheep, goats, and camels to the agricultural lands farther south during the latter part of the year, after the rainy season had ended and the crops had been harvested. This time, however, the migrations not only were starting much earlier than usual, but were much more intense.

The influx of unusually large numbers of nomads at an unexpected time gave rise to anxiety among the governments of the six Sahelian countries. The nomads brought stories of widespread suffering in the northern regions owing to the virtual absence of precipitation during the previous several months, when the rainy season (June-September) normally would have renewed northern rangelands in preparation for grazing livestock herds. The dearth of rainfall during the current year, added to that of the previous four years, had caused rivers and wells to run dry, pasturelands to give way to desert, and men and animals to die from thirst and hunger in the Sahel's vast, remote northern reaches.

In May 1973 an FAO fact-finding commission reported that at least five million and possibly as many as ten million people inhabiting the stricken area faced certain starvation within the next few months unless emergency food and medical supplies could be gotten to them without delay. Foreign journalists dispatched to the scene confirmed the magnitude of the disaster: The drought had already destroyed 50 percent of the livestock in Mauritania and 40 percent in Mali. The Sahel was strewn with the carcasses of animals that had perished for lack of water and fodder.

Thousands of nomads bereft of their herds — the mainstay of their existence — were fleeing to the already overcrowded towns and cities of the Sahel in search of food and water and the possibility, however remote, of finding a new livelihood. The refugees, by their sheer number, created serious urban problems with which local municipal authorities were ill prepared to cope. The more fortunate — those who still possessed a few animals — fled southward by the thousands in quest of water and whatever meager pastureland might still be left to sustain their famished herds. This sudden and massive invasion by human beings and animals into farmlands farther south, which had themselves been only marginally productive, provoked new crises, as disputes arose between sedentary peoples and the newly arrived nomads over land and water rights.



[Photo: Agency for International Development.]

Refugee camp in Niger.

Major Factors Contributing to the Drought

This catastrophic situation was the result of three major factors: (1) climatological changes; (2) disruptions in the ecological system caused by improper land use by man and increasing human and animal populations; and (3) the absence of adequate water control projects.

Climatological changes. In recent years the Sahelian and Sudanic areas have been undergoing important climatological changes. In the northernmost Sahel there is great fluctuation in the amount of rainfall which can average anywhere from 5 to 20 inches per year. Moreover, such rainfall is apt to be received in a few major storms of great violence but of brief duration. Under such circumstances, most of the rain is lost in runoff and rapid evaporation. During the last five years, rainfall has progressively decreased in many parts of both the Sahelian and the Sudanic regions, and in 1973 it fell to the lowest point so far.

Many pasturelands which in normal times could expect an average of 25 inches of rain received in 1973 less than four inches. The Senegal, Niger, and Chari Rivers, whose overflow during the rainy season irrigates countless fields along their banks, in 1973 never even reached their crests; indeed, the Niger and Senegal Rivers and Lake Chad were at their lowest level in recorded history. Many of their tributaries went almost completely dry. Lake Chad, 4-10,000

square miles in area (depending on seasonal variation), used to form one of the greatest natural reservoirs in Africa. But by May 1973 it had diminished to one-third its normal volume, and, in fact, had almost broken up into two much smaller bodies of water, barely connected, and replenished by the feeble inflow of the Chari River. Meanwhile, tens of thousands of human beings and their livestock competed with wild animals for what was left of the great lake's waters.

Another indication of important climatological change is the growing irregularity of rainfall during the last five years. The rainy season normally runs from mid-June to September or October, coinciding more or less with the growing season. People planted seeds in June with some assurance that by October they would be able to harvest crops. But since 1968 this pattern has been undermined. In region after region, farmers sowed their crops after an auspicious beginning of the rainy season only to find that their seeds did not sprout because the first rain was not followed soon enough by a second or a third. In the Upper Volta, particularly, local farmers' seed supplies became depleted and food shortages in various parts of the country were severely aggravated.

An example of irregular rainfall can be observed in Niger. There, in the region of Agades, the annual rainfall over the last 30 years through 1968 has averaged seven inches during a 24-day rainy season. In 1969, however, the area received only three inches of rain, and in 1970 it decreased even further, to 1.5 inches. Although in 1971 rainfall increased to 3.6 inches, this was still only a little more than half of what the region had received during the previous three decades, and for reasons that still remain a mystery to meteorologists, the rainy season contracted from an average of 24 days to a mere 14 days.

Some meteorologists have attributed the present drought to a general decline in rainfall discernible in many parts of the world; others link it with the unusually high pressure systems in the Arctic which are producing long-term climatic change as well. At a symposium held at the University of London in July 1973 to discuss the crisis in the Sahel, Professor H. H. Lamb of the University of East Anglia presented a paper which suggested that over the first half of the twentieth century a high pressure belt surrounding the outer limits of the polar regions appears to have had the effect of moving all other climatic zones a few degrees of latitude nearer to the equator. If Professor Lamb's hypothesis is correct, then its implications for the Sahel are of vital importance. As another British meteorologist, Derek Winstanley, recently wrote, "Because of the low mean annual rainfall and the strong north-south rainfall gradient in the Sahel, . . . a southward shift of the climatic zones of only 1 percent latitude in 100 years means a decrease in rainfall of some 40-50 percent."

There is a paucity of pluviometric data for the Sahel prior to 1930. What data exist suggest that there is a cyclic pattern repeating at 30-40 year intervals. Thus the Sahel suffered from a serious drought during the period 1908-1913 and again in 1940-1943. But in neither of those instances was the overall impact of the drought so severe as in 1968-73.

Disruption of the ecological system. A second major factor in the crisis in the Sahelian-Sudanic zones has been the disruption of the ecological system caused by overgrazing and improper land use.

Overgrazing has been particularly destructive in the Sahel because excessive animal populations exert demands on land resources which cannot be satisfied. There used to be a rough equilibrium between the number of domestic animals — cattle, goats, sheep, camels, and others — and the support the land could offer them. Over a period of centuries the nomadic peoples had developed, through natural selection and crossbreeding, hardy strains of animals adapted to the Sahel's harsh climate and sparse rangelands. The nomads and their herds lived in a kind of symbiotic relationship with the sedentary populations farther south who cultivated millet and sorghum and other grains which are staples of the region. Traditional migratory patterns had gradually evolved: the livestock herds moved in the rainy summer months into the sparse rangelands of the Sahel, and in the dry season went down into the pasturelands farther south in the less arid regions. Thus nomads would bring their herds down to graze in the agricultural lands after the crops had been harvested. The farmers welcomed the pastoralists, because in exchange for the forage which their animals consumed (regarded by the farmers as a waste product) the animals deposited manure to fertilize the fields.

A problem emerged when this state of natural equilibrium began to be altered as a result of programs implemented by the Sahelian governments and various foreign aid groups. Immunizing and worming cattle and otherwise improving the health and quality of the animals led to a marked increase in the livestock population. By 1970 the six Sahel states had population of some 24 million and about the same number of animals, which was about one-third more people and twice the number of animals as the land was carrying 40 years before. [Note: the peak years for cattle numbers in the Sahel appear to have been in 1965-67, i. e. they had started to decline before the impact of the drought.]

The increase in livestock among pastoral peoples such as the Tuareg, Peul, Berabiche, and others, was regarded by them as a form of economic security against the day when bad times would occur. Insofar as the African governments were concerned, larger numbers and healthier strains of livestock were understandably regarded as an

important asset, and, increasingly, these came to represent a major element in the respective economies. In the Upper Volta, for example, livestock accounted for nearly one-third of the country's exports by 1972.

At the same time that livestock populations were increasing, other variables were adding to this disequilibrium which were not duly recognized, either by the Sahelian governments or by the well-intentioned foreign governments and international aid agencies whose assistance had increased the livestock populations. Chief among these variables was that while the total number of livestock increased, the amount of pastureland available to support them started to diminish owing to the increases in population and the extension of cultivated areas. Further reduction in pasture resulted from the sharp decrease in rainfall between 1968 and 1973.

The granting of independence in 1960 to the territories of the Federations of French West and French Equatorial Africa also contributed, indirectly, to this disequilibrium. Independence converted into separate sovereign states the vast areas that had been under unified control of the French government. These new governments moved quickly to establish controls along their borders (in many cases these borders had never been clearly marked). These efforts brought in new artificial restraints: different codes of laws, separate nationalities, laissez-passer requirements, etc., which impeded what up until then had been the free movement of people and animals across lands which had few natural frontiers. The Tuareg, for example, had moved freely in northern Mali, southern Algeria, Mauritania, or Niger, their movement dictated only by concern for finding water and pasture for their animals. Now the Tuareg found that they were subject to constraints which were entirely foreign to their experience. In Mali and Niger, and to a lesser degree Chad, programs were even taken up whose implicit or explicit aim was gradually to force the pastoral populations to become sedentarized. Inevitably, such measures first restricted, then diminished, the amount of land available to the pastoralists and their herds.

Another change was occurring simultaneously. Many of the sedentary populations, which in times past had been occupied almost exclusively with agricultural pursuits, now started to acquire domestic animals and fowl in growing numbers in case of food shortages. This meant that local farmlands formerly open to pastoralists after the harvest season were no longer available to them or available in diminished amounts.

Thus the pressure of animal and human populations on the limited land resources gradually grew more intense. The situation reached a crisis level when, beginning in 1972 and continuing into 1973, the lack of rainfall throughout most of the Sahel dried up huge areas of

rangeland that normally could have sustained large numbers of livestock. The result was a massive movement of nomads and their herds southward at a time when the farmers, themselves seriously hurt by the lack of rain, were in no position to receive them.

Improper land use. Another important cause of the damage to the ecosystem of the Sahel is the harmful land practices in this part of the world. In some areas, for example, the pressure to increase cash crops has led to reduction in the fallow periods of crop rotation, with consequent erosion. Another harmful practice is the slash and burn technique.

The age-old method of clearing land in Africa has been to cut vegetal cover with machetes or similar implements and then set fire to the accumulated debris. This practice has contributed significantly to erosion in the Sahel and elsewhere on the continent. The problem is less serious in the Sahelian zone than in the Sudanic zone, where the slash and burn technique is more widespread because the grass and other vegetal cover is thicker. The principal danger is that brush fires, once started, are often impossible for the individual to control. They spread far beyond the limits that the farmer himself envisaged, and destroy vegetation on land which he is unable to utilize or on which other people's crops are planted, unless firebreaks (cleared strips) are built to stop them.

African governments have been fully aware of the problem, but they have been virtually powerless to do anything about it. To enforce existing laws prohibiting the starting of brush fires as a means of land clearance would require vast surveillance systems and equipment which these governments simply do not possess and cannot afford. In the absence of means for enforcing the anti-brush fire laws, African governments have sought to teach the peasant populations that it is in their own best interest not to employ such practices. But more often than not, efforts at dissuasion have failed utterly for the simple reason that the average African peasant is too poor to possess any but the most primitive tools for clearing land. Yet his survival depends on his ability to clear the land on which he grows food. Quite naturally, he resorts to what seems to him to be the cheapest and least laborious method of getting the job done: he burns off the land.

A more serious threat to the ecosystem of the Sahel comes from the uncontrolled cutting of wood, which has resulted in widespread destruction of the limited forest resources of the area. This problem is not unique to the Sahel but is common to many parts of the world with extremely limited wood and vegetal cover. In those areas of the Sahel where trees are found at all, they play an extremely important part in the conservation of national resources. Not only do

they recycle nutrients which exist deep in the soil, but their foliage also provides a constant source of humus. Moreover, they play a key role in anchoring the limited amount of top soil to the ground and thereby act as a check against wind and water erosion.

In the Sahel, the threat to the wood resources, unlike that in the more humid coastal areas farther south, does not arise from the massive cutting of trees for purposes of commercial exportation. Rather, it comes mainly from the use of wood as the principal cooking fuel. The existence for centuries of relatively large agglomerations of people in urban centers has over time resulted in the gradual depletion of wood supplies in circles of ever-increasing radius centering on the towns and cities of the Sahel. This depletion has directly affected the lives and living standards of the inhabitants of these areas in two important ways: it has brought a gradual decline in fertility of arable lands, as erosion progressed; and it has caused a steady rise in the price the consumer has to pay for wood fuel. A study published in 1965 concerning the town of Kano in northern Nigeria estimated that almost three-quarters of the city's firewood, which totaled some 75,000 tons per year for a population of 300,000, had to be hauled in from a radius of about 20 kilometers. In Quagadougou, Upper Volta, so intensive has the deforestation been that virtually all the timber stands within 70 kilometers of the city have been completely exhausted. The average Voltaic household now has to spend 20-30 percent of its total yearly budget for the purchase of fuel.

This heavy pressure of human populations on the area's limited wood resources can only be expected to get worse. Over the last few years the towns of the Sahel have shown a rapid rate of growth — an average of 10 percent per annum. And with additional thousands of nomads streaming into the Sahelian towns and cities as a result of the recent crisis, their rate of growth can be expected to increase further.

Water Control Projects

Though the Sahel contains some of Africa's most important bodies of water, including the Senegal and Niger Rivers and Lake Chad, there exist few water control projects such as dams, irrigation canals, and other water catchment and storage facilities. A few such facilities were built by colonial authorities before World War II in connection with large-scale agricultural development schemes, but no major dam or other large water control project has been built since that time. This is not surprising in view of the extremely limited financial resources available to the Sahelian countries. Water control projects to irrigate lands which are only semi-fertile at present are all the more important because, unlike the Nile, neither the Senegal nor the Niger carries down from its tributaries great amounts of silt to add to the fertility of the soils adjacent to the river bank areas.

Governments in the six states of Sahel have initiated minor water control projects. Sometimes alone, sometimes in conjunction with foreign governments and international aid agencies, they have dug deep bore wells, for example, in regions where there are oases or important settlements. In addition, individuals have built small earthen dams and dug pits or shallow wells to catch surface runoff after rainstorms. To the extent that these have supplied the local people with at least some water, however inadequate for total needs, they have been a crucial factor in their survival. Most of the water catchment devices built by individuals are crudely built and lose a major part of their water (50 to 70 percent) through evaporation. Neither the deep wells built by the government nor the smaller projects of individuals are suitable for meeting the long-term needs of the agricultural development that is indispensable to genuine economic progress. Some critics allege that the sinking of too many such wells, particularly in the areas of heavy population density, has resulted in a critical lowering of the water table and thus in the subsequent development first of greater aridity, then of desertification.

The problem of controlling water resources in the Sahel has been rendered more difficult by the reluctance of the various African governments, until the present crisis descended on them, to cooperate effectively. Sahelian governments have tended to think of development in a national rather than a regional context. Several international commissions have been established for developing water resources, but they have often been thwarted by impediments of a political nature, by the lack of trained personnel, or by the difficulty in obtaining adequate international financing for their projects.

A case in point is that of the Senegal River Basin Commission. This organization, known by its French initials OERS, was founded in 1964 by Senegal, Mauritania, Mali, and Guinea with the aim of jointly undertaking projects for the development of the Senegal River Basin. These projects included, among other things, the construction of four major dams: the Delta and Galougou Dams on the Senegal River, the Gourbassi Dam on the Falémé River, and the Manantali Dam on the Bafing River. These dams, if they could be completed, would augment appreciably the water reserves of the four countries and increase the amount of their arable land through irrigation, and would provide them with new sources of electrical power.

The organization never made any headway, mainly because of political differences between President Sékou Touré of Guinea, on the one hand, and the Presidents of Senegal, Mali, and Mauritania on the other. The other leaders of the OERS decided to dissolve the organization and to form a new one without Guinea; in 1967, they formed a new group called OMVS whose goals were essentially the same. So far the new organization has achieved little more than its predecessor, although the program for the new dams has been

under study for ten years by government groups and international organizations, and documents relating to its feasibility and advantages have been prepared. Part of the problem has been financial. Given the extremely limited financial resources of the Sahelian states, major water control projects will require massive financial assistance from external sources. Various reasons have been responsible for difficulty in raising outside funds: the weakness of the natural resource base of the countries concerned; the relative underpopulation of the areas in which the dams would be built; the absence of transport and communications facilities to complement the industrial base that would be laid by the construction of dams and electrical power installations, etc. In view of the present drought crisis and its sympathetic coverage in the world press, however, financial assistance for the Sahel may at last be obtainable.

The Physical Consequences of the Drought

The disruption of the ecosystem of the Sahel due to the conditions mentioned above has had disastrous consequences for the natural environment of the entire area. The most serious of these consequences have been the lowering of the water table, an increase in erosion, and the progressive desertification of many parts of the Sahel.

Lowering of the water table. It is not possible to speak in general terms of a uniform decline of the water table for the Sahel as a whole, as the area is much too vast and the situation may vary significantly from one subregion to the next. However, scattered investigations indicate that in some areas it has fallen by as much as 50 to 100 feet.

So scarce have the rains been in many parts of the Sahel over the drought years that even some of the region's greatest bodies of water have gone almost completely dry for protracted periods. During the first few months of 1973, the water level of the Niger at Bamako, capital of Mali, fell so low that the city's hydroelectric works, which pump drinking water and furnish electricity to the city, were almost completely immobilized. In Niger, the once magnificient oases of the Telwa Valley in the region of Air are in a state of advanced desiccation owing to the virtual absence of rain over 1972-73, and the resulting lowering of the water table.

In Chad, the great lake of the same name has receded in places over 15 miles, leaving behind a vast sea of mud in which thousands of wild animals, desperately struggling to reach the ever more remote body of fresh water, got trapped and perished on the spot. As Professor Edwin S. Munger of the California Institute of Technology has pointed out, however, the shrinkage of the lake is not entirely due to low rainfall in recent years. There has gradually been occurring what geographers call a "river capture" by the Benué (Niger system) working

back towards Lake Chad. This "capture" of the part of the southern and wetter basin of Lake Chad would have affected the level of the lake regardless of rainfall totals.

According to a recent study of the hydrology of the Sahel undertaken for the United Nations Development Fund by a French expert, M. Drouhin, even if the rains should return to their pre-1968 figure, it would take five to eight years for the water tables to return to pre-drought levels.

Erosion. Overgrazing, perpetuation of slash and burn methods, uncontrolled woodcutting and destruction of other vegetal cover, the virtual absence of extensive and effective water control projects, and a steady decline in the water table — all of these factors have exposed the Sahel to a process of erosion. The Sahel is susceptible to infrequent but sudden rainstorms of great violence and to the continuous wearing effects of the harmattan, the searing wind that blows down from the Sahara Desert, and these natural phenomena render it all the more vulnerable to erosion.

Another major cause of erosion has been the intensive traffic in areas of limited vegetation. The problem is apt to be particularly acute in areas adjacent to or in the vicinity of water points where animal as well as human concentrations are heaviest. The passage of large numbers of people or livestock over a given area results in the destruction of the grass cover underfoot and in soil compaction. These in turn prevent the subsoil from retaining the rainwater needed to permit the renewal of plant growth, thus stripping away one of the last defenses against erosion.

A study prepared by AID dealing with the development and management of the steppe and brush-grass savannah in the Sahelian zone mentions that statistics on the extent and significance of soil erosion in the region are virtually non-existent. The same document goes on to state, "A study of a similar region in Algeria concluded that more than half the crop land and pasture land (in that country) have been seriously damaged by water or wind erosion. In the Steppe area, the denudation was estimated to be about 1 mm. of soil per year where the soil is resistant, and 2 mm. where sandy." The AID report, published in 1972, estimates that approximately 250,000 square miles of arable land, previously suitable either for agriculture or for intensive grazing, have been lost to the Sahara desert in the last 50 years.

The effects of erosion become more serious when one considers that at present the population of most of the countries of the Sahel has been growing at the rate of almost 2.5 percent per annum, which implies that it would double roughly every 28 years. The simultaneous

action of these two factors — a diminution of land resources and an increasing pressure on these resources owing to growth of the population — points to a further deterioration in living standards unless new directions in development are initiated with extensive aid from the outside world.

While bearing in mind the ominous trends which are present in the Sahel, it is also important to achieve a broader perspective on the question. As Professor A. T. Grove of Cambridge pointed out in a paper delivered to the 1973 Symposium at the University of London, deserts are not expanding everywhere in Africa. Indeed, there are areas where irrigation and afforestation have been successful in converting what were formerly desert lands into verdant crop lands for the use of man and his domesticated animals. Therefore the process of desertification is not irreversible although any attempt to reclaim land from the desert is apt to be extremely costly.

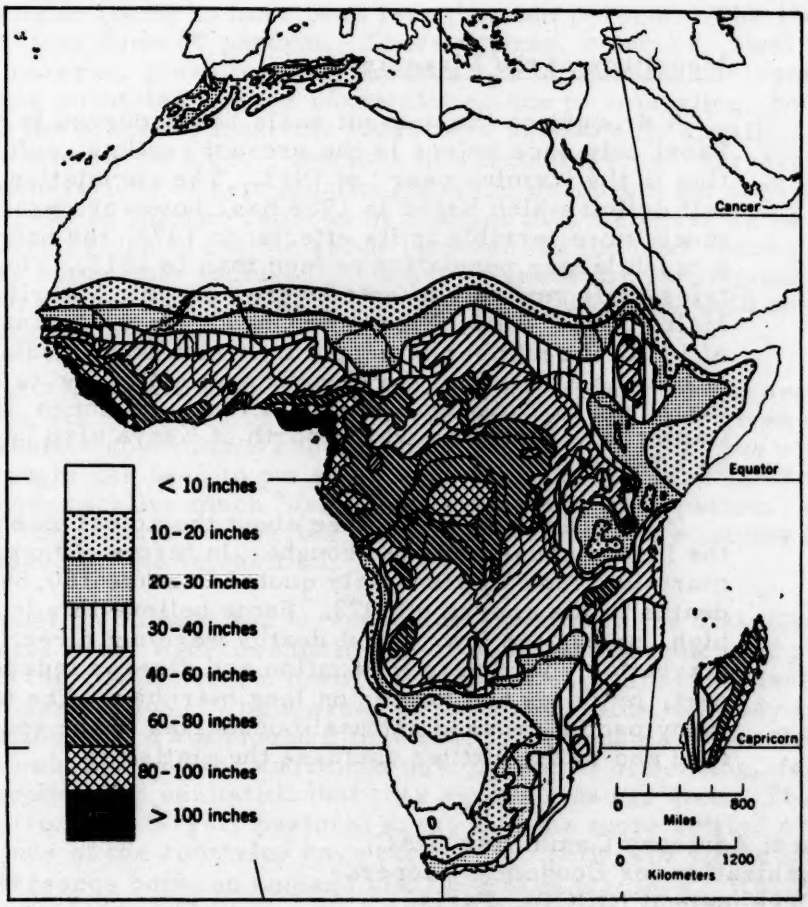
Given proper management and a return to pre-drought pluviometric levels, it is quite probable that the Sahel could support a human population comparable in number to that which inhabited the region prior to 1968. What is not likely — and this is a factor of crucial importance — is that it could support the same animal population using the same technologies, given the climatic uncertainties. And this important qualification implies a restructuring of the nomad economy which would have important social repercusions on the pattern of nomadic life.

Nevertheless, it is important to note that the Sahelian governments have formulated a range of proposals for buttressing their countries' defenses against the effects of future droughts. These plans range all the way from such ambitious schemes as the building of dams across their major rivers and the planting of forest belts to protect against further desert encroachment, to more modest proposals of digging village wells and providing better food storage facilities. Successful implementation of these plans will require self-sacrifice and mobilized effort on the part of the peoples of the Sahel. It will also require an understanding of the Sahel's problems on the part of the outside world and a willingness to help resolve them.

[Extracted from The Drought in West Africa, published by the American Universities Field Staff, New York, West African Series, Vol. XV, No. 1. Copyright©, American Universities Field Staff, Inc., 1974.]

Note: Since this article was written in 1973, the 1974 rains returned to approximately normal levels in areas when they were measured. Whether the effects of the 1968-73 drought have produced a premanent diminution of land resources, as frequently stated, is a difficult question. In the northern Sahel, where seasonal grasses come and go with the annual rains, the boundaries of the desert are fluctuating every year in remote areas from which few data emerge. In the areas of permanent grasses further south, local impacts of erosion can be serious but not necessarily irrevocable; recovery after the rains return is slower, and sometimes brings in inferior vegetation. It is too early to distinguish the long run ecological results of the drought.

ANNUAL RAINFALL ZONES IN AFRICA



Disaster Relief in the Sahel

OECD - DAC

[In response to the disastrous Sahel drought, the countries of the area have undertaken emergency measures and a wide range of foreign donors have provided large quantities of food and other supplies. Further, the Sahel countries have agreed on a comprehensive program for economic recovery and further development.]

Magnitude of the Disaster

A drought on the present scale has occurred in the Sahel only once before in the present century, culminating in the "famine year" of 1913. The cumulative rainfall deficit which began in 1968 has, however, proved much more terrible in its effects; in 1973, the Sahel had a much larger population to feed than in 1913. The countries most severely affected were Senegal, Mauritania, Mali, Upper Volta, Niger and Chad. By the beginning of 1974, the number of people in Africa in immediate need of help as a result of the drought was estimated to have increased to 7 million, as the Gambia, Northern Nigeria, Cameroon, Ethiopia and the north of Kenya also began to be affected.

It is difficult to be precise about the actual extent of the losses caused by the drought. In terms of human mortality, one figure widely quoted is some 100,000 deaths in the course of 1973. Some believe this is too high, others too low. Most deaths were not directly from starvation, but due to exhaustion and disease induced, in part, by thirst and hunger on long marches. The fact that many people crossed national boundaries in the search for food and water further confuses the statistics.

Development Advisory Committee (DAC)
of the Organization for Economic Cooperation and Development (OECD), Paris.

The Commission of the EEC estimated livestock losses as of December 1973 as follows: Mauritania 60 percent; Senegal 23 percent; Niger 20 percent; and Upper Volta 18 percent (no estimates are available for Chad and Mali). These overall figures, however, reflect considerable local variations. In Mauritania, for example, in certain areas 80 to 90 percent of the cattle have been wiped out, and in some parts of Niger 60 to 80 percent, while in Mali hundreds of cattle-raising families have lost their herds entirely. The term "losses," however, includes not only those animals that succumbed through lack of food and water, but also those that were slaughtered and the meat consumed, and those driven into other countries. French experts estimate that between 500,000 and one million head of cattle may have entered Nigeria in this way, and Senegal may have received as many as 300,000 from Mauritania.

The EEC figures indicate the shortfall in cereal production in 1973 as compared to a normal crop year as 72 percent in Mauritania, 50 percent in Senegal, 42 percent in Chad, and 37 percent in Mali. In Niger and Upper Volta it seems to have been less than ten percent. The rice crop in Senegal was down 60 percent. These figures, however, must be treated with due reserve, given the very small scale of much subsistence farming in these countries and the uncertainties due to smuggling, hoarding, etc. Whatever the exact fugures, the losses are undoubtedly appalling and recovery cannot but be slow. The loss of a breeding-cow represents a loss for five generations of reproduction, and the prospects for food crops next year will be further reduced by the fact that the peasants have frequently been driven to eat the seeds intended for the next season's planting. This sometimes included not only the seeds for subsistence farming but for export crops as well. Senegal, for example, sold only half its peanut crop in 1972-73.

The FAO has estimated that the drought has slashed the average GNP of the six countries by about 50 percent, an estimate given also by the Sahelian governments themselves. In other words, the effect of the drought has been to put these countries, which were already stagnating economically, much further back than they were before. In the process, the various tendencies already at work in the economy have been speeded up and intensified.

The most significant and far-reaching example is the dissatisfaction within rural life. With the continuing drought the movement of population from the country to the town, already a steady flow, suddenly became a mass exodus. Whole areas of the countryside, already denuded of vegetation, were abandoned altogether. At the same time, the towns were overwhelmed by the enormous new problems of housing, feeding, water supplies and sanitation that they suddenly had to face. These migrations from the largely pastoral areas into the more settled and populous regions of the countries have thrown into relief the ethnic and political differences between nomads and sedentary farmers. When, destitute and rootless, tribesmen came crowding into the urban centers to beg

for food, the black Africans of the south, with ancestral memories of the slave trade, were often not too moved to help them in their distress. The tented "towns" on the outskirts of capitals and other urban centers that had to be hastily improvized and serviced by the government and army authorities, polarized with dramatic suddenness the irreconcilability of two very different modes of life.

At the same time, the plight of the nomads threw into new relief the decreasing viability of much of the nomadic herding tradition. Conceived of originally for unlimited space, the practice of extensive herding was doomed to disaster as the herds became bigger and the pastures progressively more exhausted. In the same way, the drought has speeded up the decreasing viability of the traditional extensive dry farming. Very little had been done in the preceding years to irrigate the land. Perhaps the most serious respect in which long-term trends have been accelerated by the drought is the damage to the environment.

Emergency Relief

Once the governments of the Sahel countries finally appreciated the magnitude of the disaster, they found themselves faced with two tasks of almost equal urgency. The first was provision for the starving thousands who were streaming into the towns; the second was to get the country-side producing again. Both would have taxed the resources of governments with far greater financial means and more experienced administrative and technical services. The Sahel governments had to deal with them, with their revenues depleted by these same disasters that were driving the refugees into their midst, and in circumstances of unprecedented social and economic upheaval. The authorities did what they could. To cope with the immediate emergency, they organized distributions of foodstuffs, instituted solidarity campaigns which collected a levy of one day's salary a month, tried to organize food distribution and suspended the cattle tax. (The severe budgetary loss that this latter measure represented was made good to a large extent by the EEC).

The Sahel governments have since come in for considerable criticism in the international press for the slowness of their reactions to the fact of disaster. Against the charge that they could have acted earlier, it can be said that the countries hoped each year that the next season's rains would bring relief. There was, further, the human reluctance to public admission of helplessness, reinforced in this instance by the pride of not-long-independent African states. When aid-financed emergency supplies began to arrive, the national governments, most of which had set up special institutional machinery to handle the crisis, themselves assumed responsibility for their distribution. However, without satisfactory storage and warehousing facilities, with inadquate transport infrastructure and an administration totally inexperienced for dealing with such an emergency, the operational problems were immense.

The second task was to get the next season's crop sown, almost as important for survival as emergency feeding. Emergency programs were accordingly begun, consisting of well-digging and repair and completion of existing boreholes. The refugees in the camps were offered several weeks' rations to induce them to go back to their land in time for next season's planting, and were provided with seed, some of it air-lifted in. The most significant step the governments took, however, was to set up joint machinery to handle the Sahel problem on a regional basis.

Emergency food aid from other countries to relieve the distress caused by the drought had been provided to individual Sahel countries since 1968. In that year, Mali, Niger and Senegal appealed to the United States for emergency food rations, and between mid-1968 and mid-1971, the United States contributed over $13 million of food, and some further $3 million was contributed by other donors. The World Food Program provided 57,000 tons of cereals at a cost of $8.9 million, the biggest WFP action ever. In 1972 the emergency shipments increased, with more donor countries and international bodies participating.

The international community did not begin to gear itself to major relief action until a joint appeal from the six Sahelian governments on March 27, 1973. By the end of October 1973, however, a total of 525,000 tons of grain had been provided. In November 1973, the United Nations and the FAO jointly launched an appeal for a further 500,000 tons of food and $30 million in cash for health programs, seeds, transport, storage facilities, animal feedstuffs, veterinary supplies, etc. But by February 1974, the Ouagadougou countries themselves were speaking in terms of a food deficit of the order of 1.2 million tons.

To arrive at an accurate assessment of total requirements, both in foodstuffs and other emergency needs, is extremely difficult (because of the distances involved, the impossibility of predicting the next season's crop, official attitudes which, for different reasons, may tend either to play up or play down the extent of crop failures, smuggling, etc.) It is also difficult to make an accurate assessment of what has actually been provided at any given point in time, the complications here being the administrative ones of accounting procedures, pledges versus deliveries, pipeline delays, etc. However, according to figures available, the international community provided to the Sahel a total of over 1.2 million tons of cereals — up to October 1974 — from the following sources (Table 1).

[The latest tabulation of financial contributions by foreign donors is shown in a table at the end of this article. In all 62 nations plus international and private groups supplied over $400 million in emergency aid.]

TABLE 1: GRAIN SHIPMENTS TO SAHEL COUNTRIES BY MAJOR SOURCES

	Up to Sept. 15 1973[1] (a)	Nov. 1973 to Oct. 1974[2] (b)	Up to Oct. 1974 (a+b)
Canada	26,000	39,000	65,000
China	50,000	11,000	61,000
France	62,000	74,500	136,500
Germany	32,000	35,000	67,000
United States	207,000	232,375	439,375
EEC	103,000	110,000	213,000
WFP	57,000	33,481	90,481
Others	90,000	76,912	166,912
Total	627,000	612,268	1,239,268

SOURCES:

1. Status of grain shipments to Sahelian countries as of September 15, 1973, FAO Newsletter No. 8.

2. Report No. 11 on the drought in the Sahelian region and the emergency operations undertaken by the United Nations system, FAO Office of Sahel Relief Operations (OSRO), September 10, 1974.

Medium and Long-Term Rehabilitation

The Inter-State Committee representing the six Sahel governments, after a series of meetings at expert, ministerial and heads of state level in September 1973, gave their approval to what has subsequently become known as the Ouagadougou Program for the rehabilitation of the Sahel. This consists of 123 project proposals costing an estimated $850 million. The Chairman of the Committee, General Lamizana, the President of Upper Volta, asked the United Nations for help in its financing, and described it as a "Marshall Plan for the Sahel."

The Program covers actions to be undertaken by each country for the medium term, defined as a recovery period of three to five years, by which time it is hoped that the countries will have returned to where they would have been if the drought had not occurred; and for the long term, where the aim is essentially to identify the basic causes of the ecological disruptions and ways of preventing their recurrence. Together, they comprise measures for water control and development; extension and intensification of irrigation farming; research into plant varieties to find those best adapted to the area; environmental protection

(prevention of deforestation, rehabilitation of degraded areas and resettlement); and meteorological research in order to gain a better understanding of climatic trends. Some of the activities involved will need to be planned on a regional basis, e. g., the major programs of river, road, rail and air transport, and the major hydraulic projects which will regulate the flow of the Sahel's rivers. The programs for afforestation and improvement of pastures will also need to be designed as a function of the requirements of broad climatic zones rather than on a national or local basis.

The task confronting the Sahel governments could hardly be more daunting. It involves, in effect, putting a check to the southward march of the Sahara and, at the same time, reducing the isolation and neglect that for centuries have been the lot of the backward, inland communities of western African. Can it indeed be done? If the recent climatic evolution presages a continuing long-term trend, then the process of desertification will in time swallow up not only the Sahel but will encroach on the savannah further to the south. At a conference on desertification held in Nouakshott in Mauritania at the end of 1973, experts predicted that the present weather cycle might last 50 years.

Most development specialists seem to believe that even if the worst prophecies prove to be justified the Sahel countries could still salvage an area sufficient to feed their populations and could, moreover, move forward into development if appropriate action is undertaken. A final victory over the desert, however, presupposes first, that the strategies are right, second, that the financial, technical and administrative resources required can be mustered for their implementation, and thirdly, that the several individual actions that will be involved will be undertaken in the context of a coherent and continuing global approach.

The means that the Sahel countries will need to have at their disposal in order to implement the strategies can be summarized as follows: first, major and sustained foreign help; second, administrative and technical skills; third, field-level advisers and extension workers to assist in propagating and consolidating the desired revolution in agricultural and livestock techniques; and fourth, a consistent and determined will, both on the part of the governments, who will need to continue to place the achievement of broad regional strategies before considerations of partisan politics, and on the part of the people in terms of taxation and in the relinquishing of cherished traditions. None of these elements will be easy to secure and still less to maintain. Nevertheless, the Sahel countries can count on a number of assets which will facilitate their task.

First, they will not be starting from zero in all these activities. In several domains a very considerable amount of preliminary research has already been undertaken, and the results of the various

studies and experiments are either already available to show the way or at least can serve as the basis for further investigation geared to specific area needs. This is the case, for example, in the fields of selected plant varieties, irrigated farming in the main river valleys, and systematic livestock production. A great deal of work has been done on the flow of the major rivers and their tributaries, and a number of specific hydraulic programs have already been prepared. Similarly, research already under way in the meteorological field will provide a basis for further study.

Secondly, in some of these areas of activity there already exist the necessary regional structures. This is notably true in respect of the major river development projects, where associations grouping the riparian states concerned had been created before the drought.

Thirdly, science and technology can assist the Sahel today in a way undreamed of a generation ago. The United States NASA satellites are already monitoring meteorological data, infra-red photography provides now means of prospecting (for both minerals and water) and the use of solar energy for irrigation is another possibility.

Finally, it is quite possible that the shock and disruption caused by the drought disaster to the traditional patterns of life in the Sahel may itself have created a climate more propitious to rational change than existed in the more settled past. Many of the nomad tribes have already been uprooted. Further, the now recognized need to remain within access of assured supplies of water will enforce, of necessity, some degree of localization of the herds (and the herdsmen) and thus make possible the introduction of more intensive cattle-rearing practices. At the same time, the government authorities in these countries are themselves sensitized, as they have never been before, to the vital need to reform the economic, social and political structures of their country and of the ways in which this might be done.

[Extracted from Chapter 6 of Development Cooperation: 1974 Review, pp. 103-110. Paris: OECD, November, 1974.]

FINANCIAL CONTRIBUTIONS TO SAHEL RELIEF THROUGH SEPTEMBER - NOVEMBER 1974 (in millions of dollars)

National			
Argentina	1.9	Sudan	1.85
Belgium	2.9	Sweden	4.7
Canada	14.6	U.K.	4.2
China	10.9	U.S.S.R.	6.6
Denmark	2.5	U.S.	228.2
France	24.3	Other[a]	4.0
West Germany	14.9	International	
Italy	2.0	Arab League	18.0
Japan	3.2	EEC	37.5
No. Korea	1.5	U.N. Bodies[b]	0.5
Netherlands	1.1	Non-Official[c]	
Norway	3.15	Red Cross, Churches, CARE, etc.	15.8
Nigeria	1.1		
Pakistan	1.85	Total	$407.25

a. 43 nations contributed sums of less than $1 million each; total donor nations - 62.

b. UN funds only; the larger sums given through the UN are identified here by national source.

c. Understated: includes only private aid from the U.S. and international groups, while that from other countries comes under national totals.

SOURCE: Compiled for a forthcoming publication of the U.S. Agency for International Development from UN/FAO, U.S. Government, Red Cross and other sources.

A Sectoral Approach to the Cattle Industry in West Africa

Frank D. Abercrombie

[Cattle production and marketing in the Sahel countries can become more efficient than it has been in a number of respects. This article describes a strategy for improvement, treating the region and the industry as a whole and focussing on geographical zones rather than countries.]

The rapidly narrowing margin between beef production and beef requirement is particularly critical in Africa, where the level of protein intake is the lowest of any region in the world. Given the anticipated demand for beef and the inadequacies of the present system to meet this demand, immediate steps must be taken if this trend is to be reversed. This paper is an attempt to present one strategy for dealing with the problems of beef production.

As the cattle industry in West Africa is presently structured, various stages of livestock activities are associated with distinct geographic zones. The zones primarily used for producing and growing cattle encompass the bands of dry steppe (Sahel), and bush (Sudan) just south of the Sahara; while the Guinea Zone or tropical rain forest — which occupies a band stretching along the coast from the Senegal River eastward — contains the major consumption areas plus a small number of finishing facilities (abattoirs, fattening ranches). A more intensive development of finishing activities in this zone is prohibited largely because of the tse-tse fly. Maximizing the special capacities of each zone could offer a coordinated approach for improvement of the total industry. Such a strategy would recommend: improving

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the production of immature animals in semi-arid zones; developing several means of finishing animals for market in the higher rainfall areas; providing transport to and processing facilities for the main consumption centers.

The Production and Marketing System

Production. West Africa can generally be divided into two areas. The beef surplus area, where cattle are produced but populations are relatively small, includes Mauritania, Mali, Upper Volta, Niger and Chad. The deficit area, where populations are comparatively dense and beef cattle production is small, includes the Ivory Coast, Ghana, Togo, Dahomey and Nigeria. Only Nigeria has both a substantial domestic production and a large level of import.

There are an estimated 23,000,000 beef cattle in West Africa, but the annual offtake (i. e. the numbers sold from a herd) is less than ten percent. These animals are produced at high cost. Calf mortality is high; 40% never reach maturity. Animals mature late and are usually not sold until six years of age. Nearly 15% of the animals die enroute on the long trek to markets, and an estimated 15% shrinkage in weight occurs. A variety of tariffs are charged in their movement. As a result, the value added to the final cost from marketing charges alone is 50%, of which half is taxes.

Mortality from disease limits beef production. While widespread mortality from rinderpest seldom occurs due to large-scale immunization campaigns, trypanosomiasis (carried by the tse-tse fly), bovine pleuro-pneumoinia, and protozoan diseases continue to cause large numbers of deaths and debilitation within herds. Quality beef production is inhibited by the traditional husbandry practices of the nomad herdsmen which reflect greater priority for producing a large number of hardy animals than for producing high grade beef.

Caution must be exercised, however, in disturbing present production systems through partial development programs without considering the entire socio-economic system. Much of the occupational division between pastoralists and farmers is based on tribal precedence, with a long-standing system of interdependence between them. Traditional livestock producing tribal groups have developed systems of production which are often complicated as to timing the movement of animals in order to provide feed and water with the least danger from disease, predators, parasites, and conflicts with other tribal groups or government authorities. Nevertheless, as the expansion of cultivation continues to remove land from pasturage it can be anticipated that there will be an increasing competition between herdsmen and farmers for the same land, use of water wells, etc. Deterioration of much of the grazing land in the

drier northern zones is accelerating this process. Because their occupations are traditional, the potential antagonisms between farmers and herders pose problems for governments and development planners in designing livestock and agricultural activities in these areas.

Demand. An FAO report suggests that by 1975 all of Africa, apart from Egypt, Sudan, Somalia and South Africa, will have a beef deficit between 180,000 and 330,000 tons. This gap will widen with the human population increasing continent-wide by 2.3% and that of cattle rising by only 2%. A wide variation exists in levels of consumption for urban and rural communities: where rural persons consume little more than 5-8 kgs annually, urban coastal persons may consume as much as 15 kgs per year. Because of rapid increase in urban populations and some rise in their real income, the market for beef, reportedly, is growing at a rate of 6-10% annually in large West African towns. Thus, by 1985 the food demands of urban Africa will be 2 1/3 times as high as in 1965. The probability of reaching production levels of this magnitude is highly unlikely unless dramatic advances in the beef industry occur. It is important to consider the manner in which Africans make use of beef. Apart from dried beef, which is popular, beef is principally used as a stock meat in stew — in the main food style of West Africa. Beef carcasses are generally cut into small cubes and sold in chunks to buyers. Virtually all of an animal, hides, offal and meat, is used and portions can be cut and sold in very small pieces which almost every household budget can afford. Beef, therefore, is a staple protein source, and when used in this way has important implications for grading. Older and tougher meats are entirely acceptable. The one requirement is that the meat is fresh and preferably lean. Because Africans have no means to preserve meat, aside from jerked or dried, beef must be used as soon as possible after slaughter. The marketing system, therefore, must deliver a live animal as close to final consumption areas as possible. The value added from freezing or chilling puts the price above most average households, and it is a new item which still encounters consumer resistance. Since the lowest income consumers are the principal buyers of offal and hides, the movement of frozen or dressed carcasses would automatically exclude these parts which are within the budget of poorer consumers.

Markets. The movement of cattle in international trade is shown in Table 1. Nigeria is fast becoming the primary beef market of West Africa because of its large population and increasing wealth. The Nigerian market now reaches suppliers in Mali in competition with the Ivory Coast.

The marketing systems vary according to governmental policy and other factors. Some consuming countries, or transit countries such as Upper Volta, have levied import, transit and other tariffs, which has raised the cost to final consumers and reduced industry profits. Inland countries

seeking to increase their share of the value added by international markets, are frustrated by such taxes and policies. The higher value export market also militates against consumers in the exporting countries. In Mali, for example, domestic buyers are unable to bid successfully against the wealthier export markets and generally must accept fewer and poorer animals. But if Mali inhibits export to retain a greater domestic supply it will lose badly needed foreign exchange.

TABLE 1: CATTLE TRADE BY COUNTRIES - 1971
(in thousands of head)

Importing Countries	Niger	Upper Volta	Mali	Chad	Mauritania	Total
Ivory Coast		55	85		20	160
Togo	7	3				10
Dahomey	8	2				10
Ghana	10	25	25			60
Nigeria	165		15	150		330
Total	190	85	125	150	20	570

It is difficult to generalize about prices and the allocation of value among producers, marketers, tax collectors and sellers, but some figures are suggestive. For an animal of good quality moving from Mali to the Abidjan market, the producer seems to earn 57% of the final wholesale value, the marketers some 13%, 11% go to taxes, and 8% to interest on invested capital. A typical cattle trader appears to move three or four herds annually. In this case, total cost to the butcher is probably 37,000 Fr cfa ($160) and its wholesale value 40,000 Fr ($172). These shares seem to vary considerably. A maximum of fourteen different taxes have been levied against the movement of animals overland to coastal markets. Such taxes may include: buyers' license, market tax, municipal tax, sanitary inspection fee, charge for certificate of origin, and fee for export permit. In addition, there is an export tax, an import tax, and, in some cases, a transit tax. At the abattoir a market tax is levied, an abattoir tax, a sanitary inspection charge, and perhaps another official tax. As a result, a large share of costs to marketers are for taxes, 45% if sold in Abidjan, 35% if sold in Lagos, and 53% if sold in Lome.

In several countries retail price ceilings are imposed to keep the cost of living down for urban consumers. Often there is a flourishing

black market: for example, it is estimated that over half of all slaughters are "unofficial" in Bamako. Where the ceiling is effectively enforced, as in the Ivory Coast, rising costs of operation are pushed back to the producers who then get a declining share of the final price.

Transportation. Treking is the major means for moving meat to consuming areas. Meat processed outside of consuming areas has traditionally been transported by air because refrigerated cars or trucks are not available and rail and roads are not geared to rapid delivery. Existing roads and rails are used to a limited extent because of high costs, uncertain availability of cars or trucks, and the excessive time required for delivery. In the Ivory Coast some 40% of cattle go by rail, and in Nigeria the percentage is close to 50%. In both countries the share by rail is decreasing due in part to a shortage of rolling stock and the low relative value of cattle compared with other goods. In Togo and Dahomey, however, the rail service is important to the industry. Only in Northern Ghana is truck transport significant, but this follows from the regulation that animals may not be moved out of medical check areas on foot. Several institutional factors limit its use. For example, in the Ivory Coast, apart from long truck delays at the border (a total of six check points on both sides), virtually every town has a transit charge on passing trucks. As a result, the road transport costs are very expensive.

Most animals are therefore moved on foot, which is both time-consuming and costly in terms of herd survival and weight loss. However, treking retains its importance since it is one way to avoid frontier formalities, and since there is often no other alternative for animals which must be moved from remote places. This practice will inevitably continue to result in most animals arriving thin and sick because of the long overland trek, often without adequate forage facilities and other health requirements.

Development Emphases In The Different Zones

Modernization of nomadic production in the semi-arid zone (Sahel and Sudan). Programs to develop better husbandry in and more efficient use of the semi-arid zones are admittedly difficult and long-range. But they constitute one of the highest priorities in order to arrest serious depletion of both animal and grazing resources. Nomadic or rotational grazing is one of the most efficient ways to utilize much of the semi-arid rangeland. Development programs need to capitalize on this system and encourage more efficient use of land and water through comprehensive mapping, water development, land use arrangements, and controls on size and distribution of herds. Husbandry improvements must respect the traditional objectives of cattlemen (prestige, milk, security), but can also offer incentives for adopting practices more suited to meet the growing demand for beef. These programs, along with disease control, should contribute to the growth

of herds without causing deterioration of the land. In comparing nomadic grazing with controlled rotational grazing inside a large fenced range area (which has been tried in a few places), the former is better adapted to the erratic localization of rainfall in the Sahel and it can employ many more of the existing Sahelian populations without capital costs.

There have been many unsuccessful attempts to improve nomadic livestock production. Most of these have had difficulty because they attempted to settle nomads against their inclination, developed only one aspect of the system (e. g., water) without adequate controls over uses of the surrounding land, or failed to relate to other social or economic needs of the pastoralists. Nevertheless, several programs have shown positive results and provide guidance for future development. Experience gained from tribal grazing ranches in Northern Nigeria, Southern Ethiopia, and Northeastern Kenya indicate that a plateau of production may be reached about the 7th year after development. An annual offtake of 15-16% is about the maximum possible where such ranches are operated for production of steers to desired slaughter weight, with sales of surplus heifers, cull bulls, and cows. However, this increase from 5-8% to 15-16% offtake represents an increase of over 100%.

The other system possible on grazing reserves or ranches is the production of immature steers for sale to growing and fattening ranches in higher rainfall areas. This gives a faster turnover of male animals in that steers are sold at 1 1/2 - 2 years of age and it allows a higher percentage of the herd to be foundation breeding stock. On ranches with good management practices and disease control, offtakes of 20% can be expected. This strategy seems particularly appropriate for the semi-arid regions of West and Central Africa.

Finishing for Market in Higher Rainfall Zones (Guinea or transitional Sudan)

Several alternative methods of finishing for market may be examined in terms of the agronomic, economic, social, and disease factors in each location.

Ranches. Ranch schemes to increase the number of animals available to market are economically feasible only where the value of alternative crop enterprise is so low that land may be used extensively. Animals need so much grazing land that such activities usually are possible only in remote and thinly populated areas. As cities and towns expand, land formerly used for cattle is often converted to crops. Land tenure problems can be nettlesome if one attempts to expand cattle ranches in cropped areas. In West Africa, the best opportunity for small ranches will likely develop as areas

are cleared of the tse-tse fly — in effect, as new frontier is opened. Unless cooperatively owned or utilized by herdsmen, such ranches will have to pay sufficiently high prices for cattle to induce the nomad not to trek his cattle closer to the principal consumption centers.

Some basis may exist for a livestock cooperative in the private sector or a joint public-private venture. The basic viable economic unit for such an operation might be 20,000 acres and over 10,000 head. Stock could be bought from the nomads for finishing or rearing. However, such ranches in Chad and elsewhere that specialize in finishing have not been markedly successful. Capital requirements have been high. It has been difficult to obtain the necessary land or to isolate managed range and water from nomads. These ranches are in effect beef plantations operated as an enclave. They usually have few effects on the immediate economy and probably are not popular locally. But there may be some promise for these in newly opened land.

Experience in West Africa and elsewhere indicates the following requirements for success in ranch projects. 1) Sufficient land must be available in order for an economic unit to be put together. This means that in most cases ranches will have to be in relatively remote, thinly populated areas. 2) The necessary total capital requirements and phasing of capital inputs are vital and cannot be so excessive that they preclude a rational investment. If capital requirements can be planned in such a way as to make annual requirements modest, the project would have a higher likelihood of success. 3) Good management is essential. Where few local ranchers are veteran cattlemen, adequate technical assistance is vital. 4) The role of government in the success of such a scheme is very important. If it is half-hearted or if the government is weak in its approach, the attempt should not be made. 5) The veterinary service must be adequate and available. 6) The market structure must be able to cope with the large quantities of animals that will be produced.

Improvements on treking routes. The establishment of servicing areas along the treking or market routes has the advantage of fitting into present production and marketing practices and allowing the herder more flexibility in marketing his cattle. However, it requires regulated offtake and stocking rates, provision of forage and water at designated locations, enforced control of disease and parasitism. The United States, Australia, Argentina, Kenya and South West Africa have all depended on such systems. In the first three countries the system is now replaced by rail or truck operations. But until such time as rail and roads are constructed and suitable equipment made available, the traditional system will prevail in Africa.

To maintain weight or to promote growth enroute to market requires disciplined systems of movement — movement of animals on schedules

that will make maximum use of available feeds, forages and water. It requires fixed resting areas stocked with feed and water that are not overcrowded. It requires meticulous health control — a regime of disease and parasite prevention applied and enforced at appropriate intervals in the trade routes. In most of Africa, it will require trypanasomiasis control in the fixed corridors of movement. These corridors must be defined in relation to available sources of feed and water (see discussion below).

Mixed farming. South of the nomad zone but north of the tse-tse fly zone is a transitional area where rainfall is sufficient to permit farming, one crop per year, often on a shifting basis. This land is shared with pastoralists who retreat to it during the dry season. There appears to be some scope for the diversification of these farms to include either a livestock enterprise or a pure finishing operation. This would amount to managing crop lands in conjunction with grasslands. Additional research into dryland farming will be needed, however, before one can be in a position to recommend such multi-enterprise schemes and the needed package of inputs to farmers. Farmers would have to be trained in husbandry skills and in the necessary agronomic practices. It is likely that a combination of supervised credit, extension, and input supply would be required. Nevertheless, this approach might be one of the most promising in the long run, since it would not involve the land tenure problems which a ranch scheme would entail. Also, it need not call for large capital inputs per farm, and it would create employment (shepherds would have to be employed and farm family activities extended). As comparatively intensive operations, these mixed farm sites could be located closer to urban markets than ranch enterprises.

Once suitable feeding arrangements are made, marketers might feed their cattle on these local farms. Or farms might buy cattle and finish them. These farmers would likely be far more amenable to technical guidance and far less likely to overstock their ranges. Nomadic persons desirous of settlement might find mixed farming a congenial half-way point, allowing them to retain an interest in cattle while adding a millet or maize enterprise.

Feed lots. Where a higher carcass weight or more rapid maturity and higher grade is desirable, a feed lot operation becomes a feasible addition to the production system and perhaps one with long-term export prospects as well. Few markets, however, and probably only rich coastal ones, could afford the much higher quality animal produced by a feed lot finishing operation. The location of a feed lot will depend on the economics of feed transport and supply, which varies considerably between different regions throughout Africa. It is conceivable, however, that a combination ranch and feed lot scheme can be introduced where the market structure is sufficiently strong to move large

numbers of animals and its size and wealth are adequate as in Abidjan, Dakar, or Lagos.

Marketing and Distribution Between Zones

There has been much criticism of the West African livestock marketing system as wasteful, exploitive, having an abundance of middlemen, and being a costly burden to producers and consumers alike. What is often overlooked, however, is that this system, with little public investment or involvement, works sufficiently well to place beef in the hands of most people, including the poorest. That the system cannot provide more beef at a cheaper price is as much a problem of technology, official regulations, and levels of animal supply as it is one of faulty organization. At best, the system provides employment and assembles, moves and distributes animals over long distances, and does so cheaply. Moreover, it represents a strong vested interest, and changes affecting this interest could expect to be met with vigorous resistance.

Governments could, however, take some useful steps. They could act to assure fairer prices to sellers. Price information could be posted and kept up to date; retail and wholesale prices in final markets could be made available at assembly points. This would help increase the efficiency of dispatches to these markets. Simple grading, conforming to local realities and tastes, could help pricing and set the groundwork for future improvements in quality. A grading system could be designed to assure an adequate reserve for local consumption in Mali; this would help in reconciling the paradox of inadequate local supply and large exports. Governments might also help to improve transportation of cattle by encouraging the use of large cattle trucks for animal transport. Truck transport would not put new burdens on public administration apart from normal support of roads and bridges, and with the rapid movement of animals, little weight would be lost and the chance of exposure to illness greatly reduced. A tremendous change in administrative practices, however, would have to be accomplished to reduce the many official impediments to the smooth flow of truck service.

Despite its many difficulties, the trek remains the most inexpensive method of animal movement in West Africa. Few administrative or official problems exist to impede movement on foot. However, long drives with scarce forage and water and exposure to tse-tse fly greatly reduce the value of the final delivered herd. If food, water, and disease preventative methods could be provided, the trek could remain an efficient method of animal transport. In East Africa routes are carefully marked, food and water are provided, and medical support made available. The system does put some burden on public administration, but the results include larger healthier animals delivered to final markets. High recurring costs are likely, but perhaps some combination of fly-free

trek routes and improved truck transport will be feasible in West Africa.

Processing. Many attempts have been made to locate slaughter facilities in the Sahelian Zone so that the value added could accrue to the producing countries. These attempts have not been an unqualified success, for most operate at far below capacity and a number do not function at all. In effect, the slaughter houses in the Sahelian Zone produce a product whose quality is in a sense above the demand of the local market composed of low income consumers, in that they supply a large proportion of the better exportable meat relative to the non-exportable byproducts eaten by the poor. Such houses could play an important role in the development of meat for export out of West Africa, but they seem doomed to a difficult and limited future in the regional market. Finally, the African preference and need for fresh meat gives a good reason for animals to be killed as close to the final consumer as possible. It will be some time before cooling or freezing facilities are common enough and reliable enough to become an important factor in supplying inexpensive meat to the main African market.

These factors lead to the conclusion that modern processing facilities should be built for the most part near those markets which demand high quality meat. A problem in this approach is that producing countries will want a larger early share of the income from the high quality meat going into the coastal urban markets. The solution may be intergovernmental agreements that assure equitable distribution of proceeds to the producing countries and provide for sharing the investment costs of production and finishing in the producing countries.

Political and Administrative Cooperation

If the West African beef industry is to be developed along rational economic lines, a considerable degree of regional cooperation will be required among the countries. The lack of alternatives open to the inland countries should encourage the wealthier coastal countries to support the efforts of the former countries to gain a larger share of the value of the industry. There has to be a better balance between needed revenues and benefits to provide incentives for a more vigorous cattle industry.

The Entente Common Market (Dahomey, Ivory Coast, Niger, Togo and Upper Volta) is one example of regional cooperation. In 1970 the Entente Economic Committee formed a group to deal with livestock and meat problems in creating a common market for these products, but so far the Committee has had little impact. Taxes for member states have been increased by ten percent since 1967 and are equal to almost half of the marketing costs of beef. The Economic Community for Livestock and Meat presented a proposal to the Council

of Ministers in July 1972 which would have changed the multiple tax structure into a more equitable and simplified form with some reduction in total levy. This proposal was rejected by the Council. A second grouping is the Lake Chad Basin Commission comprised of Cameroon, Chad, Niger and Nigeria. With objectives and organs similar to the Entente, the group has some promise of developing rational ground rules for livestock movement and a commercial beef industry. These groupings and others like them are a promising start in regional cooperation, but their promise still exceeds their actions in promoting such cooperation.

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Agricultural Production in Mali

Martin Billings

[Agricultural development of the Sahel is possible, as illustrated by analysis of the conditions and opportunities in Mali. Two key elements are water control and energy (animal power can be important). But national financing and skills are so very limited that outside assistance is badly needed.]

With a per capita GDP of $60-70, Mali ranks as one of the world's poorest countries. Malian public revenues are meager, mainly derived from export and import taxes. A national budget of $30,000,000 cannot cover recurrent costs, and nearly 90% of the investment for growth in the current plan depends on external finance. Since independence the country has barely been able to keep ahead of natural population increase (2.3%) to sustain a net cumulative growth of perhaps one percent per year. The drought has been a serious setback, especially in livestock but also in staple food production.

Mali has traditionally been self-sufficient in grains and at one time an exporter, and it has the technical (if not economic) potential of becoming a major cereal producing center in West Africa. But a number of 'ifs' stand between Mali and realization of its potential. If productive technologies could be developed and incorporated into Malian agriculture that were physicially feasible, profitable and of acceptable levels of risk, and if sufficient markets could be found, and if an acceptably cheap transportation system were installed to move goods, and if neighboring countries were to cooperate by opening their markets to Mali, and if skilled manpower needs could be met, then Mali might realize some portion of its promise. Lacking these in full measure

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Mali will have to content itself with the reconstruction of an agriculture that can meet present and future domestic needs. Just to do this will require considerable external assistance.

The rate of population growth is believed to be increasing as a result of improved health measures; there was a 50% increase in population since 1950 to about 4 million. Cereal consumption has always fluctuated widely with the harvests; but average year-long availability of rice, millet, sorghum and wheat has declined (calculated from quite crude figures) from an estimated 260 kg per capita in 1961-63 to 220 kg in 1970-72. Per capita meat consumption in rural areas is low (20 kg per capita) and is likely declining as a result of the drought, but may be offset to some extent by fish and game. As a consequence of this trend Mali has become increasingly dependent upon food imports which — though still small in proportion to consumption — more than doubled in the past decade. This paper will examine critical aspects of farm production in Mali with special attention to cereals.

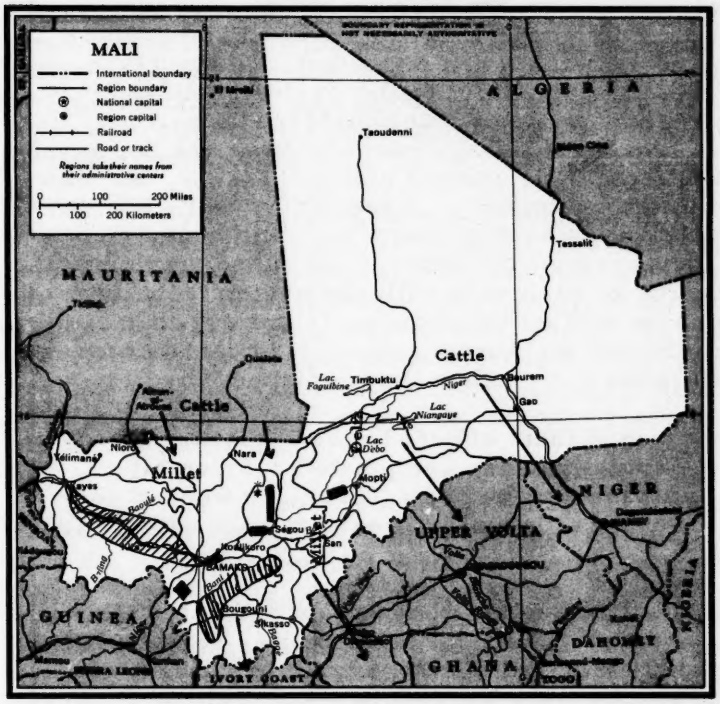
Agricultural Regions

Mali is a butterfly-shaped country that sprawls across several environments — from moist savanna to very arid desert. The northern wing of the country is an agricultural zero, suitable only for extensive pastoral activity and some limited cultivation immediately adjacent to the river. Mali is a dry country with rainfall ranging from 1300 mm, in the extreme south to 400 mm, in the northernmost region; however, agricultural conditions are affected by the presence of the Niger River, which flows for 1700 km across the country. A substantial portion of this river and its tributary, the Bani, regularly overflow their banks, and at one point they join to form the vast interior delta which extends north from Mopti across a network of lakes almost to Timbuktu. The river makes possible the irrigation of large areas and provides excellent pasture during the dry season and an abundance of fish.

The river aside, Mali's agricultural regions roughly conform to levels of rainfall. The northern-west and central regions (map 1) are of mixed millet and peanut cultures with some local tobacco, vegetables and rice — the latter along the rivers. Cattle are raised in much of the area on an extensive basis. There is considerable local potential in several locales, but these are remote from markets. Transport is especially poor in this part of the country.

The lands south of the Niger, perhaps the most advanced part of the country, are the heart of the Malian cotton industry. It is also the most densely populated. Most of Mali's surfaced roads are here. In addition to cotton, sorghum, millet, maize, fruit and vegetables are grown.

MAP I - CROP OF MALI



Much of Mali's immediate agricultural potential may exist in the delta area. The zone is now a center for cattle finishing (before trekking to coastal markets), millet and paddy rice. Better use of the water in the delta, most of which now goes to waste, could greatly extend the output of cattle and rice. In recent years intensive rice polder development has gone on near Mopti and Segou. In addition there is the territory of the "Office du Niger" (see below), north of Segou, where on 50,000 hectares is grown much of Mali's rice and all of its sugar.

In the longer run, if financing becomes available, Mali hopes to build several important dams. These would make possible significant extensions of irrigation, bulk water transport, cheap electric power, and in time some industry. But no dam project could have any production effect for at least five years, and the largest one will take a decade to complete.

The Crop Production System

In common with most African farm systems the Malian is composed of numerous small farms on lands occupied by lineages of families.

Member families are provided sufficient land on which to sustain themselves, but individual land ownership does not exist. Resources, land and labor are viewed as joint goods between extended and nuclear families; reciprocal labor contributions are important. In any given locality there is little variation in wealth. Wealth derives mainly from the quality of a community's resources so that considerable regional differences are probable. Important lineage persons often are the focus of such "wealth" as derives from their special claims to labor, but with concommitant obligations to the community. Hereditary wealth and permanent skewness of its distribution are not the practice in such a economy. The Malian rural social system provides welfare and employment for most citizens. To attempt to replace it with any system equally effective would require a cadre and investment vastly greater than Mali could mount. Like the traditional marketing system it is best left alone and helped to become more effective, rather than replaced.

Malian farmers devote most of their efforts to the subsistance production of coarse grains. Typically seeds are planted 3-5 per hill, 16,000 hills per hectare, all prepared by hoe. These are weeded and thinned depending upon the supply of labor. Cereals are cut with a hand scythe and threshed by hand.

Separate development organizations have been responsible for promotion of the cash crops, and with considerable success. Perhaps 20% of Malian farmers devote some land to the commercial production of cotton or peanuts. Animal traction has been an important element in the cotton program: 75% of the land under cotton is plowed; manure and fertilizer are used. It is likely that elements of improved tillage have been picked up by some grain farmers from observing cash crop methods, but the hoe and scythe remain the primary technology in cereal production and fertilization is not common.

Energy. There appears to be adequate land in Mali, although its general quality is low. The critical constraint to extra production, apart from sufficient moisture, remains labor. Man-supplied farm energy is very scarce on the widely dispersed farms. The available of draft animals, which has become quite widespread in Southern Mali, has no doubt been the principal factor permitting the growth of cotton cultivation, and their use could be of importance elsewhere.

Farmers put 90% of their land under cereal crops. Moisture and weeds are critical determinants of final cereal yield. Dense weeds can reduce millet yields (commonly 450 kg per hectare $\pm$ 100 kg) by half. Given the nature of cereal culture, weeding must be done by hand. Observers note that Malian farmers allocate scarce labor as a function of availability of moisture. When it is deficient, they weed cereals intensely. If abundant, they cultivate their cash crops and weed cereals less, (as extra moisutre has sufficient yield effect to offset the effects

of extra weeds). If Malian agriculture is to be changed, much more needs to be learned about the availability of labor throughout the year, especially during peak demand periods; the requirements of different crops and activities; the extra output possible from extra energy investment, and the opportunity costs to energy of particular activities. A better understanding of farm incentives and perceptions of risk are needed.

The traditional agriculture is losing the race to keep up with absolute population growth. It is likely that the best lands, both in terms of soil and moisture, have already been taken up. Evidently the system is at maximum output now given water and energy supplies. Increases in cereals can only be at the expense of cash crops and vice-versa. A real investment in dryland agriculture research is needed; work on manures, erosion, forage, mixed enterprises, water management, all-year cropping, economic sources of extra energy — all must be studied.

Cash crops. Two French companies have undertaken applied farm research and extension — the CFDT for cotton, and the BDPA for peanuts. The former has been especially successful: it selected a good cotton variety and did the necessary adaptive research in Mali to produce a satisfactory crop technology. An adequate extension service was organized which was able to advise and was provided with the means to perform its tasks. Draft animals, equipment, seeds, fertilizer, etc. were made available with supervision of their uses. A guaranteed market was provided, and a price was paid that covered production costs and risks and supplied the necessary incentives. With animal energy farmers have been able to add new land for cotton, which has reduced the substitution affect against cereals. Farmer participants were provided a "package" including animals and their equipment on condition that proper practices were followed. If, after 2-3 years, farmers wanted to purchase the package they could at a very reasonable price. The result of this approach has been a very rapid spread of cotton culture. The experience of BDPA in the expansion of peanut production was similar.

The practices which adaptors were encouraged to follow include: 1) improved land preparation; 2) use of manure; 3) use of improved varieties and early sowing; 4) careful weeding and inter-row cultivation; 5) regular spraying. This set of practices was promoted through direct extension, through the use of demonstration plots on village commons, and through regular young-farmer training schools. The new practices when applied in comparison with traditional methods of cotton culture provided a dramatic and visible increase in yields under technical and economic conditions practicable to farmers, and produced a viable cotton program. But there have been problems. Although cash has been available, devaluation reduced the supply of

consumer goods and raised their price, reducing the incentive value of cash. There have been some problems in obtaining timely supplies of inputs, in particular fertilizer, and a serious training problem is not yet fully resolved.

Cooperatives. In addition to the company supply structure, a cooperative system exists which was initiated after independence when the government attempted to promote, for the long run, a cooperative agriculture. Essentially the cooperatives were set up to replace the private trade network. The units were given monopoly in both the sale of cash crops and the sale of consumer goods. In addition such cereals as were marketed were supposed to be assembled through the cooperative outlets. Cooperatives were not a source of credit. The system was seen as one way for the government to reach farmers and as an extension vehicle. In practice little was extended, supplies were short, there was insufficient financing, and management was predictably weak. Farmers greatly reduced their marketings during the period. In recent years there has been a de-emphasis away from the cooperatives, and private trade is again permitted.

Water. Some of Mali's best prospects for increased farm production lie in efforts to improve flood-retreat cultivation. Malian farmers resident along rivers have traditionally sown immediately after the ebb of water from the summer rains. In some areas a type of polder water control has grown up. Since 1970 several rice projects which employ this system, supplemented by pumps to improve water control, have been created. A scheme near Mopti, which cost $7 million, employs low lift irrigation and careful water management which have provided a four-fold increase in rice production (from 42,000 tons to 180,000 tons): partly from increased yields and partly from greatly extended area.

Large scale irrigation projects have all encountered high costs and difficulties in management, supply, markets, etc. On a less ambitious scale, a number of opportunities exist to employ low lift pumping to irrigate perimeters a few hundred meters immediately beyond the banks of rivers. Water can derive from both the river itself or from the associated water table. For example, in the Haute Vallée project above Bamako tobacco, kenaf, cotton, vegetables and rice are grown with pump irrigation. But fuel costs and difficulties in maintenance cloud the economic and technical practicality of motor pumping. Pumps not working during critical growing periods can easily ruin an entire crop. There is great need for a reliable and economic pumping system. Animal-powered pumping would seem an alternative. The persian wheel, for example, could provide an alternative which is cheap to build and maintain, and would give an additional use to draft animals.

Agricultural Support Organizations

Mali does not now have a meaningful national research organization, nor is extension well organized. An organization does exist but it does not have much transport support or much to extend. Research and extension are performed by the companies CFDT and BDPA (now almost entirely Malianized); but these operations are limited in scope and areas, although there has recently been some attempt to broaden these company programs to include grain and cattle. The "Office du Niger" does the research and extension in its territory.

Without question this organization is the most elaborate development scheme ever attempted in the dryland zones of West Africa, and it has had a very checkered experience in its 30 years. The scheme began in the 1920s with a pilot project near Bamako where 3,000 hectares of rice and vegetables were cultivated with canal irrigation and 6,000 colonists were settled. Planners foresaw a settler community on irrigated land becoming an "island of prosperity" in the Sahel, and expanded the project. A barrage was built (Markala) and nearly 300 km of canals dug, 50,000 hectares were put under cultivation tilled by nearly 40,000 settlers. Close to $200,000,000 had been invested by independence.

The Office du Niger has never lived up to promise. It has far more infrastructure than is used in the area cultivated: the hydraulic basis for several hundred thousand hectares is in place, as well as a staff of some 2,500. Moreover, colonists are subsidized as an incentive to remain, and the settlers do have a superior standard of living to those outside. The Office has at least three operational problems. Its essential engineering is faulty so that there are persisting irrigation and drainage difficulties. There is a serious lack of manpower: the Office has conspicuously failed to attract sufficient settlers, even when persons from other countries were invited. Too few Malians appear interested in setting up a whole new way of life, even at a higher living standard. Lacking workmen, the Office has attempted extensive mechanization which only added to costs. Finally, the attempts to increase production through intensive cultivation have failed to produce proportionately to cost and effort.

The Office was given immense autonomy; it manages its people and lands as a separate entity outside normal government. It has a monopoly of marketing in its zone, a lavish basic investment in structures and has been the product of intense effort. Yet results remain disappointing. Government is perplexed as to what to do with the Office: it can scarcely drop it given the importance of its output; but it is hard to justify any expansion, and it is losing money as it is. There is a present effort to produce sugar (and crush it), expand rice, and add

cattle, all under capital- and management-intensive conditions. The experience of the Office is one to reflect on, as Mali is presently contemplating schemes not dissimilar in their demands for good engineering, labor, management, and finance.

In recent years Mali has made considerable efforts to expand output of export crops and rice through rather well coordinated area-specific projects on a smaller scale, officially termed "Operations." These Operations purport to be full-scale rural development projects involving local persons, cooperatives, credit, extension and so on in the context of market, supply, and incentive support. Until very recently food crops had not received equal attention apart from rice, but that may be changing as millet schemes are initiated, especially in the 600-400 mm rainfall zone. This form of organization is the focus of Mali's current planning in agriculture for the medium run, with large dam projects featured in the longer run.

Ideally each Operation will attract either a specific donor, or parts of the activity will be supported by one donor; Mali has few resources to invest. It can provide personnel; but transport, fuel, training and technology for the most part must come from abroad. Present plans call for Operations to be autonomous bodies, able to pay unique wage scales and organize themselves and their work to conform to the particular needs of their areas. The approach is appealing in that it frees the field work from the tedium of government channels. On the other hand, it means that Operations and government will be simultaneously bidding for personnel into a very limited job market. If Operations are not to be crippled by lack of trained persons expatriates will likely be needed in the beginning. Conceivably government could find it difficult to retain skilled personnel if alternatives were available. In practice Operations may find themselves involved in much practical conflict on the ground with other established public bodies: jurisdictional conflict seems unavoidable. It is altogether likely, as occurs elsewhere, that such schemes over the course of time may be forced to make considerable jurisdictional adaptations to local necessity. The skill of the individual Operation managers will determine in large part the final nature of their activity.

An equity issue may come into play as well. By its very nature, a strategy of selecting leading local areas and concentrating resources in them to produce large early results will require that leading farmers and better areas be identified and helped. The result clearly will be the rapid advance of some farmers and some locales. To the extent production is oriented to expandable foreign markets more farmers should be able to participate (witness cotton). But where limited local markets are the only outlet, comparative advantage will shift to well located and efficient operators. To the extent that Mali still fancies itself a socialist state the emergence of a class of comparatively well-to-do farmers may be distasteful. Regional equity

will be served to some extent to the degree that Operations can be mounted all over the country; about half a dozen have been started in different areas, and more are planned.

It is impossible to overstate Mali's critical shortage of skills. Even when able people are functioning their knowledge is often deficient for performing critical operations. There is need to train at every level, for every activity. The Operations now projected must all be staffed, and priority needs to be given to highly specific short-term training of staff at all levels. For the bigger dam projects, this kind of instruction will also be needed along with the longer term development of broader expertise.

Prices and Marketing

Since independence the government of Mali has sought to manage the price of basic food products. Government directly sets prices for millet, rice, sugar, flour, and peanut oil. Overly stringent price controls, set at a very low level, led to a serious decline in rural marketings by 1966. Since then cereal prices have been raised several times but have never caught up with the parallel private market, where off-season millet prices might be three times as high.

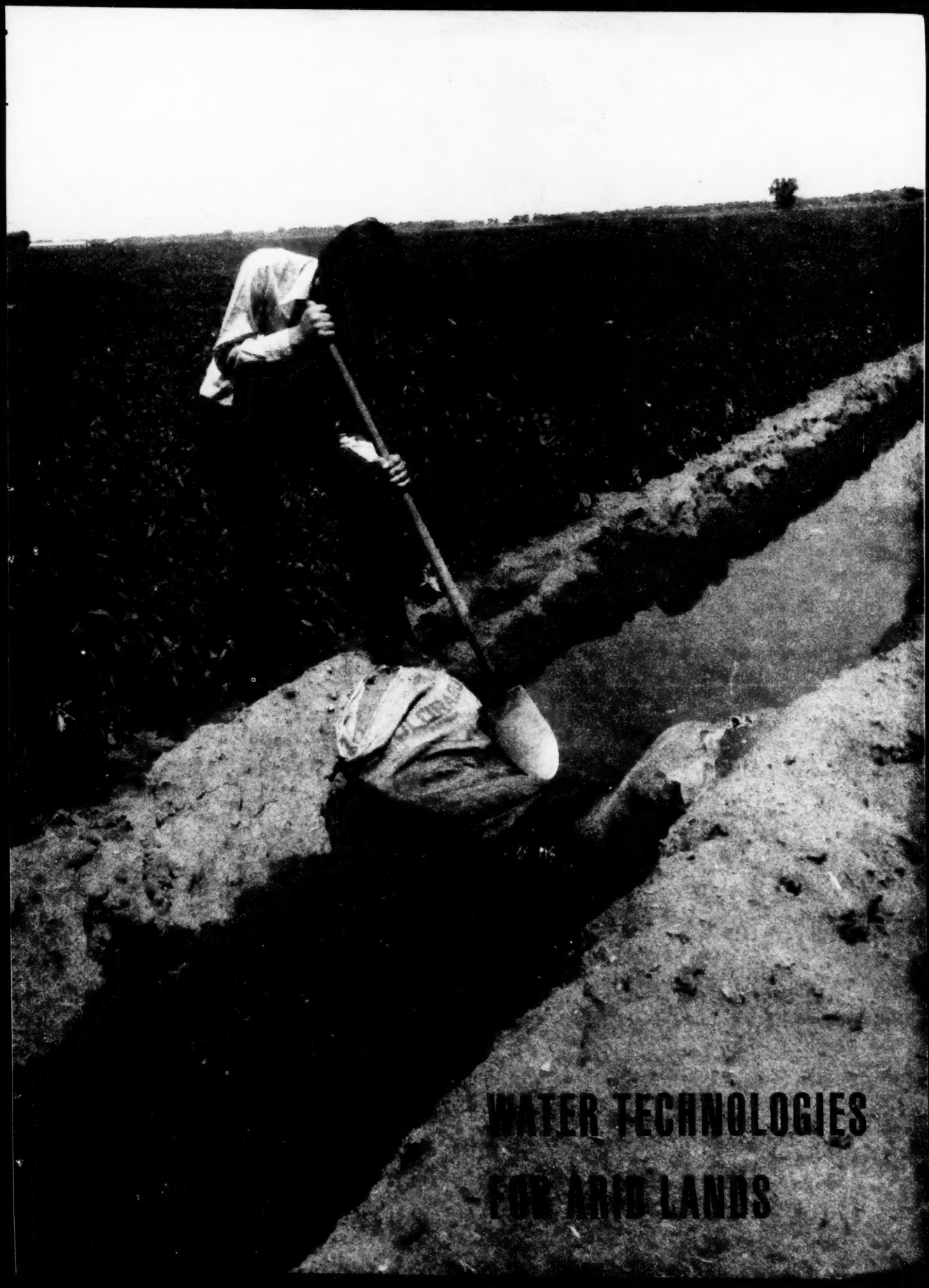
Over the same period government sought to control demand by freezing government wages; they remain unchanged for a decade despite a nearly four-fold rise in the price of cereals in Bamako while other prices doubled or tripled. The Government cannot afford to pay higher wages and does not want to ask for additional French subsidy. The supply situation has worsened as smuggling to higher-price neighboring countries has continued, with persisting high prices for cash crops, with drought, and as low prices for cereals discouraged official marketings.

It is estimated that only five percent of total millet production is marketed. Given high transport costs and the low relative value of the crop especially at official prices, a national market does not now exist. One estimate is that Bamako draws on a producing area of only 250 km radius, and other towns are much smaller. A more dense network of feeder roads, provision of market information by radio, and a better use of traditional marketing structures could help to develop national markets.

Mali is nevertheless unique amongst Sahelian states in having a nation-wide marketing organization for food grains. OPAM (Office pour les Produits Alimentaires Maliennes) is responsible for buying, storage, transportation, pricing and distribution on a national scale. Formerly in a monopoly position, it remains the preferred staple marketing organization. Law requires farmers, if they plan

to sell, to give OPAM opportunity to buy 40 percent of their potential marketings. OPAM is a high cost operation which consistently loses money. Its staff is inadequate to the task; it is deficient in storage capacity, market information, handling mechanisms, bags, etc., and it is seriously underfinanced. This said, Mali remains the only Sahelian country with a structure designed to: 1) assure its farmers of an outlet for their surplus cereals; 2) buy and store enough grains to begin to operate a stabilization scheme and reserve program; 3) move substantial volumes of grain from surplus to deficit areas; and 4) make officially announced prices effective in real markets. But the system does not provide credit or forward selling to producers, it has a difficult time buying cereals because of lack of buying points and supply of sacks, and cannot pay promptly. Internal inefficiency is so great that the market spread accruing to OPAM is 42 percent of the retail price of cereals (13 francs/kg). If this margin could be cut in half and the difference offered to farmers, the resulting price would be most competitive (over 40 francs/kg). Short-term training in marketing skills might make a contribution here.

[Extracted from an unpublished document for Agency for International Development (AID), 1974.]


WATER TECHNOLOGIES
FOR ARID LANDS

ADJUSTING CHECK POINT FOR IRRIGATION WATER
[PHOTO: U. S. Department of Agriculture.]

More Water for Arid Lands

National Academy of Sciences

[The following was extracted from a summary assessment by the U. S. National Academy of Sciences of the newer technologies that could contribute to 1.) water supplies, and 2.) water conservation methods, for use in dry areas. Some of these technologies have been relatively well tested, while others are still in an experimental stage of development. Some of these innovations would be costly or or use scarce materials, while others are more economical and could be used more widely. All of the ideas were selected as having some degree of promise for solving problems of arid lands.]

Arid regions today face more difficult problems than ever before. The world's sand deserts appear to be enlarging, and droughts are contributing to the economic devastation of whole nations. Nevertheless, arid lands have underexploited agricultural potential. We need fresh, innovative approaches to water technologies, particularly those designed to meet the needs of arid regions in the less developed world, where there has often been improper application of practices developed in regions with higher rainfall or more abundant water supplies. Also, we need to reconsider practices developed in arid regions by ancient agriculturalists.

Basically there are two approaches: increasing the supply of usuable water, and reducing the demand for water. There are many possibilities for simultaneously increasing supply and reducing demand that together will bring benefits to arid lands. A major opportunity to save water exists in conventional irrigated agriculture, by far the arid world's largest user of water. Conventional irrigation systems are not the main topic of this report, however, because they are extensively treated elsewhere.

PART I: WATER SUPPLY

Rainwater Harvesting and Runoff Farming

Rainwater harvesting is possible in areas with as little as 50-80 mm (2-3 inches) average annual rainfall. Though rain falls infrequently in arid lands, it comprises considerable amounts of water; 10 mm of rain equals 100,000 liters of water per hectare (ha). Harvesting this rainwater can provide water for regions where irrigation sources are too distant or too costly, or where wells are impractical because of unfavorable geology or excessive drilling costs.

Ancient desert dwellers harvested rain by redirecting the water running down hillslopes into fields or cisterns. Surprising amounts of water may be obtained only by digging long shallow channels and removing obstacles to the flow of water. Sometimes rainfall runoff can be collected from an untouched natural catchment; one way is to dig ponds in small depressions where they can collect runoff. Often the catchment needs modification, usually by making the soil surface more impermeable to increase the amount of runoff. (Figure 1)

Promising methods for harvesting rainwater include: 1.) treating soils with chemicals that fill pores or make soil water repellent. Adding sodium salts, which cause clay in the soil to break down into small particles (partially sealing the soil pores and cracks), increases runoff from many clay-containing soils. Sodium salts are good soil sealants because of their low cost, ready availability, and retardation of weed growth. 2.) Two coats of asphalt to make rainwater catchments (one coat seals the pores; the other protects against weathering) added on suitable slopes have been found to last 4 to 5 years. Arid developing countries that produce and refine crude oil could use asphalt to construct water-harvesting catchments. Heavy petroleum fractions such as asphalt have limited demand and are often persistent pollutants, difficult to dispose of. 3.) Granulated paraffin wax spread on the ground melts in the sun and flows into the pores to produce a surface that readily sheds water. The wax can also be melted and sprayed on the ground. Wax-treated test plots yield an average of 90 percent of the rainfall as runoff, compared to 30 percent from untreated plots. Runoff water from the wax plots had low salt content and almost undetectable organic matter.

Instead of making the soil itself the water-shedding surface, it may be better in some situations to cover it with a waterproof cover. Plastic films covered with gravel have proved most successful; the gravel protects the underlying membrane against radiation and wind damage. These catchments, if properly constructed and maintained, have a projected life of more than 20 years. They are useful where gravel is readily available and maximum runoff is not required (gravel retains some of the water).

Before a water-harvesting system is installed, one must know; a.) the soil (especially characteristics of water-holding, runoff, and erodability); b.) the topography (slope and the direction followed by natural runoff); c.) the precipitation characteristics (amount, reliability, etc.); and d.) the climate (wind, sunlight, temperature, etc.).

Because rainfall in arid lands is intermittent, storage must usually be an integral part of any rainwater-harvesting system. However, when water-harvesting techniques are used for runoff farming, the water is "stored" in the cultivated soil itself. Sometimes it is possible to build catchments to feed existing — even ancient — water-storage structures.

Surprisingly, the livestock-carrying capacity of many arid rangelands is limited more by a lack of drinking water than by a lack of feed. Rainwater harvesting may be the only source of extra water. Improving drinking-water supplies on arid rangelands or other remote watershed areas increases the value of these grazing lands and allows the available feed to be used more fully. A water-harvesting system, once installed, will provide water without requiring fuel or power.

Because rainwater harvesting depends on natural rainfall, it is no more reliable than the weather. Without adequate storage, the system will fail in drought years. In locations with an average annual rainfall of less than 50 mm, rainwater harvesting will probably never be economically feasible. Also, poorly designed and managed rainwater harvesting can lead to soil erosion, soil instability, and local floods. Soil erosion, a constant concern, can be controlled if the slope is short and not too steep. Slope also affects the quantity and quality of runoff, for the most efficient water harvest is from small, gently sloping catchments.

A rainwater-harvesting catchment must withstand weathering and occassional foot traffic. Fencing may sometimes be required. Environmental contamination must be constantly considered. Colored or contaminated runoff water will require treatment before it can be used for human consumption. Most soil treatments (especially the cheapter ones) have a limited lifetime and must be renewed periodically. They also require occasional maintenance because of cracking caused by unstable soils, oxidation, and plants growing up through the ground cover or treated soil. No one material has proved superior for all catchment sites.

Currently, rainwater harvesting is for small-scale use, for farms, villages, and livestock. The land-alteration method is ready for immediate worldwide use. Australia and Israel use it already; in the Sudan and Botswana catchment tanks have been introduced in technical

assistance programs. Chemical treatments and ground covers, though still mainly experimental, are used on a worldwide, but slight, scale. Proved to be technically feasible and successful, they are not yet economically attractive enough to generate widespread adoption.

Runoff agriculture. Once rainwater runoff has been harvested from slopes, it can be used for crop production. The combination is known as runoff agriculture. The type of farming practiced must make the best use of the water. In general, perennial tree crops with deep root systems adapt better to runoff agriculture, because they can use runoff water stored deep in the soil, safe from evaporation. Some deep-rooted, drought-resistant fruit trees can be very successful. Shorter lived crops can also be grown; grains, such as pearl millet, that mature rapidly and require only one rainfall hold particular promise. Plants that become dormant during dry periods and begin growing when water becomes available are particularly suited to runoff agriculture.

TABLE 1: Yields from Runoff Agriculture, the Negev, 1971

Crop	Tons/Hectare
Peaches	6 - 12
Apricots	3 - 8
Grapes	12 - 15
Figs	6 - 8
Almonds (dry shelled)	0.3 - 1.8
Barley	1.3 - 4.8
Wheat	1.1 - 4.5
Peas (seeds)	5.4 - 6.9
Sunflowers (seeds)	2.2 - 2.7
Alfalfa (Medicago sativa, fresh weight)	16 - 37.7
Wild Oats (Avena sterils, fresh weight)	20 - 31.2
Pistachios	0.4 - 1.8

SOURCE: Evenari, Shanan, and Tadmor. 1971

Runoff farming in the Negev desert of Israel has used channels which directed the water to cultivated fields which were terraced and had stone spillways, so that surplus water in one field could be led to lower ones. Farmers dammed the small channels between the catchment and the fields with rocks. By removing strategic rocks from channel walls they could guide the water to different fields at will. A form of runoff farming that utilizes water from small, deliberately built catchments has been practiced in Botswana.

Microcatchment farming is achieved by building a rainwater-catchment basin around a plant forcing rainfall from a larger than normal area to irrigate the plant. Each microcatchment used in the Negev Desert range is surrounded by a dirt wall 15-20 cm high. At the lowest point within each microcatchment a basin is dug about 40 cm deep and a tree planted in it. (Figure 2) The basin stores the runoff from the microcatchment, and the size is matched to the water harvest expected. The basins are fertilized with manure, and unlike the catchment area, their soil surface is kept loose to encourage water penetration. A mulch may also be used to decrease water evaporation from the soil. Microcatchments ensure the growth of fruit trees and forage plants and variations of this method are used in Tunisia for growing olives — and apparently have been since ancient times.

In the Negev microcatchment construction costs are very low — from US$5 to US$20 per ha, depending on the catchment size. The cash return from crops repays their construction costs within a few years. Microcatchments are more efficient than large-scale water-harvesting schemes because conveyance losses are minimized. In light rains, they provide runoff water when others will not. It is much cheapter to convert a given area into microcatchments than to construct a whole runoff farm because microcatchments do not need channels, conduits, terraces, and terrace walls. Also, microcatchments can be built on almost any slope, including almost level plains, enabling the farmer to use large, flat areas unsuited for runoff farms.

Desert strip, or contour catchment, farming is a modification of microcatchment farming. It employs a series of terraces that shed water onto a neighboring strip of productive soil. They are often tiered up a hillslope, but on level terrain an artificial slope for the catchment can be made by mounding soil between the strips. (Figure 3) The catchment section can be left in a natural state or cleared of rocks and vegetation, planted with range grasses, or made impervious by the sealants. Desert strips are, in general, even easier to install and maintain than microcatchments.

But runoff agriculture requires a deep soil that can store water between rains. It works best for deep-rooted crops, such as trees and shrubs, which can tap stored water and depend less on frequent rainfall. Annual crops, in contrast, need rain at the beginning of the growing season and sometimes at intervals thereafter. The method is enhanced by plant varieties able to withstand intermittently wet and dry soil. As in normal agriculture, yields also depend on insect and disease control.

Environmental prerequisites are a.) A minimum mean precipitation of 80 mm per rainy season if the rainy season coincides with the cold

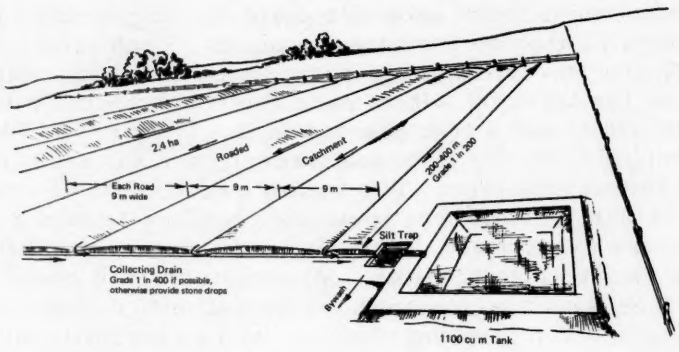


FIGURE 1. Western Australia rainwater-harvesting system. Catchments are graded and rolled and shed water with a minimum rainfall of 7.6 mm. Catchments are cambered so that rainfall runoff quickly goes to the side of the "road," where a ditch conveys it to the main-collector drain and thence through a silt trap to the storage tank.

FIGURE 2. Microcatchment farming in the Negev. Pommegranate trees grow in 500-m^2 microcatchments in a 100-m rainfall region. The only soil treatment is shaping. The orchard is less dense than those in temperate climates; 40-60 pomegranate trees per ha are planted. Smaller trees, such as grapevines, can use smaller catchments.

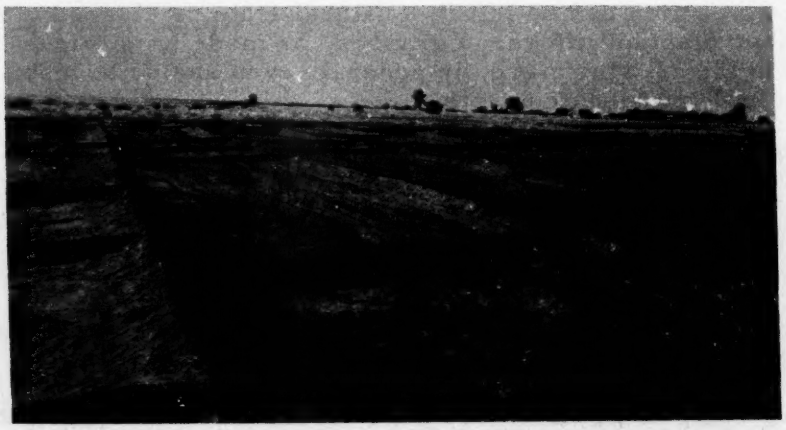


FIGURE 3. Microcatchments in Botswana with 2-year-old apricot trees.

period of the year, more than 80 mm if it occurs during summer when evaporation is greater; b.) Crust-forming or impermeable soils on the catchment areas; c.) Soils in the cultivated areas with high water-storing capacity; d.) Not more than 2-3 percent salinity in the cultivated soil; and e.) A minimum of 1.5-2 mm of soil depth in the cultivated areas (unless water-storing facilities are available).

In ancient times runoff agriculture was widespread over the whole arid region of the Middle East and north Africa. Runoff agriculture has been shown to be technically sound for modern use, too. Its rebirth as a systematic method took place in the Negev Desert in Israel, where large-scale experiments have been conducted for the past 15 years and a training school for developing countries' personnel is located at Wadi Mashash. Some microcatchment farming occurs today in Mexico, Botswana, India, Pakistan, and Australia.

Irrigation with Saline Water

Beneath many of the world's deserts are reserves of saline water, and many surface waters — estuaries, coastal lagoons, land-locked lakes, and irrigation return flows — contain fairly large amounts of salt. If saline water could be used for irrigation, more desert land could be cultivated; the nonsaline water now used in agriculture could be released for human consumption, reducing the need for expensive desalination schemes now contemplated for supplying urban areas.

The salt tolerance of crops has now been studied intensively. Although only a few crops such as cotton, barley, wheat, sugar beets, rye grass, Bermuda grass, and the wheat-grasses Agropyron elongatum and A. desertorum are known to be salt tolerant, they are important in developing countries because they form the basis of much agricultural production. Salt-tolerant trees include the date palm, olive, pomegranate, and pistachio.

In general, irrigation waters whose total dissolved solids are below 600 milligrams per liter (mg/l) may be used on almost any crop. If leaching and drainage are adequate, water from 500 to 1,500 mg/l can be, and is, widely used on all but the most salt sensitive crops. Water of 1,000-2,000 mg/l can be used for crops of moderate tolerance, especially if frequent irrigation is employed. Water of 3,000-5,000 mg/l will produce high yields only from highly tolerant crops. Irrigation with undiluted seawater has not proved practical for producing crops however. Seawater has a total salt content of about 35,000 mg/l, greatly exceeding the tolerance of even the most salt-tolerant crop studied to date — Suwanee Bermuda grass Cynodon dactylon, which can tolerate about 12,000 mg/l.

In the practice of saline irrigation, the basic premise is that proper irrigation and drainage management prevent salts from building up in the soil. It is essential to avoid this buildup by leaching: applying more irrigation water than the plant requires so that the extra water carries the salts down below the plant's roots. If the leaching characteristics of the soil particles or the overall drainage of the area are insufficient, soil salinity will increase, and the final result may be a barren wasteland. Light-to-medium-textured soils that are not subject to structural changes that restrict water flow are more likely to be successfully irrigated with saline waters. The cost of using saline water, especially from aquifers near the surface, is not likely to be excessive. At Kibbutz Mashabei S'deh in the Negev Desert (100-mm rain) a 4,800 m^3/day electrodialysis plant desalts underground brackish water. For comparison, water from the same well (2,600 mg/l) has been used to irrigate cotton, wheat, maize, sorghum, Rhodes grass, Bermuda grass, etc., and various vegetables. After 3 years, economic and general-utility considerations favor direct use of the saline water over the electrodialysis; the saline aquifer is now used for this purpose.

Although saline water irrigation holds exciting possibilities for the future, its use has so far been quite limited; most of the work has been done in Tunisia and Israel. Many crops cannot tolerate it; indiscriminate use may severely damage the soil; and suitable soil and climate do not always coincide with suitable water. To irrigate with saline water and maintain good yields demand good water management by trained specialists. The type and mix of salts and their concentrations in the water need to be investigated before a decision is made to use saline water. Saline-water irrigation will increase the salinity of groundwater and possibly make it unsuited for other uses. If poorly managed, irrigation with saline water may seriously damage the soils and even make them barren.

Even highly tolerant crops may go through salt-sentive stages when they need low-salt water. For example, seedlings of small grains and sugar beets are sensitive, though the adult plants are not. The same crop grown in temperate or humid regions can tolerate more highly saline water than it can in arid regions because rains (and soil waters) dilute the irrigation water. Lower temperature may also increase a plant's salt resistance.

Reusing Water

Reusing water can greatly lower the overall demand for water resources. Wastewater can be used for irrigation, for industry, for recharge of groundwater; in special cases, properly treated wastewater has been used for municipal supply. With careful planning, various industrial and agricultural demands may be met by purified wastewater, thereby freeing fresh water for human consumption. Water reuse may have greater

impact on the future usable water supply in arid areas than any of the other technologies discussed in this report.

Agricultural use. Spreading wastewater on marginal land to create new farm land may prove particularly important in arid countries. Filtering wastewater through soil removes all particulate matter: most cations and some anions (including phosphates) are strongly absorbed, and organic matter is decomposed by soil bacteria. These actions can contribute plant nutrients to soil. Using municipal wastewater for irrigation is especially attractive where agricultural lands are located close to cities, because the plant nutrients in sewage would otherwise go to waste. Some biological treatment of sewage should precede land application, but for many crops the degree of treatment required is so low that little technology and capital investment are required. (Mexico City uses vast amounts of untreated sewage as irrigation water.) Where irrigation systems are already in use, connecting them to municipal systems is fairly simple.

Since 1892, Melbourne, Australia, with a present population of almost 2 million, has disposed of its wastewater in irrigation at the 109 km^2 Board of Works Farm. A total of 4,200 ha of the farm is employed for irrigated pasture of which 1,370 ha are used for grazing 15,000 head of cattle through the year. Forty to fifty thousand sheep are fattened during spring and summer. Health restrictions are imposed only on the sale of cattle and sheep for slaughter. No higher incidence of disease among farm employees has been found to result from their employment. In less well-operated sewage irrigation projects in India, however, the operators have been found to have abnormally high loads of parasites.

Municipal wastewater from secondary treatment plants can also be used in industry for cooling, ore separation, and other uses that do not have severe water quality requirements. Use as process water requires advanced treatment. For pulp and paper production the use of wastewater after only limited advanced treatment has been found to be economically feasible.

Municipal use places the highest demands on water quality. Wastewater must usually undergo secondary and tertiary treatment to make it potable. Processes for removing ammonia, nitrates, and phosphates are available; residual, potentially toxic compounds and dissolved organic substances can be reduced to very low levels by absorption on activated carbon. This requires a large investment in capital equipment, power, and chemicals. The cost of such water is relatively high, but may be lower than that of desalted seawater; in arid lands it may be lower than the cost of developing alternative supplies of water, though not if treatment is needed to remove dissolved mineral salts. Windhoek, South-West Africa, a metropolitan area of 84,000,

meets its water needs by treating and recycling into the potable water supply 4 million liters per day of its sewage, which represents one-third of the total daily supply.

The important advantage of water reuse is that it can, if properly managed, reduce by severalfold the demand on water from natural sources. Continuously recycling 50 percent of the wastewater in effect doubles the water supply. In any resue scheme the major constituents of wastewater have to be considered. Pathogenic bacteria can be killed by chlorine disinfection, but the remaining hazard from viruses after advanced waste treatment is not known. Although few outbreaks of epidemic virus diseases have been attributable to transmission in water supplies, the prevailing view is that present known treatment processes remove the hazard only if very carefully controlled. Too much uncertainty exists to certify water from even advanced treatment processes as virologically safe. Though this increases reluctance to use treated wastewater for drinking or for irrigating vegetables that are eaten fresh, it should not hinder its use for less critical purposes.

To reuse water without causing environmental damage calls for good management and a good understanding of the user's requirements. Assimilative disposal of wastes on the land, which does no permanent damage, is clearly a very different thing from uncontrolled dumping, which destroys the soil and may lead to serious pollution of ground water. Too few engineers have a feel for proper rates of application to the soil. They forget that a little too much can change dilution to pollution.

As demands for existing resources in water-scarce areas become even greater, however, the potential is highly encouraging. Although the technology for reuse is now available, economic considerations will probably limit its use initially to specialized locations or purposes. Even so, such uses may release natural sources of water for potable supplies. Ultimately, as acceptance grows and the technology is further developed, widespread recycling of wastewater into the potable supply is a definite possibility.

Wells

Dug wells. Modern materials, tools, and equipment may transform crude holes in the ground, hosts for parasitic and bacterial diseases, into more safe, soundly engineered, hygienic, and reliable sources of water. Dug wells are inexpensive and easy to construct and maintain by fairly unskilled labor. They provide storage for water, as well as a source. In most cases dug wells will be superseded by the tube wells (machine drilled and lined with tubes) but they provide an important transition step, and in some cases, dug wells will always be best, e. g. , for shallow, low-yielding aquifers and for inaccessible regions where transporting drilling equipment is difficult.

Dug wells, however, do have distinct limitations: they cannot be used to reach groundwater deeper than 20-30 m; their water production is usually low; and although well digging technology is understood and used in most countries, the art of lining wells has regressed and there is an important need for improved linings. The liner protects against caving and collapse and prevents polluted surface water from entering the well. The main problem is lining the walls below the level of the water table.

Qanats. A qanat is a horizontal tunnel that taps underground water in an alluvial fan and, without pumps or equipment, brings it to the surface so that it can be used.

A qanat system is composed of three essential parts: (Figure 4)

1. One or more vertical head wells dug into the water-bearing layers of the alluvial fan to collect the water.

2. A gently downward-sloping underground horizontal tunnel leading the water from the head wells to a lower point at the surface with the tunnel acting as a subsurface drain to collect water.

3. A series of vertical shafts between the ground surface and the tunnel for ventilation and removal of excavated debris.

Because qanats deliver water without pumps and pumping costs, they can be used where pumped wells are too expensive to operate. (Figure 5)

Qanats vary greatly in length, depending on the depth of the aquifer and the slope of the ground. The conduit from the head well to the mouth may extend 1-4 km; commonly, the length is 10-16 km. A study of 200 in the Varamin plain southeast of Teheran, Iran, measured the largest yield of water at 270 liters per second and the smallest at 1 liter per second.

In Iran areas with only 150-250 mm (6-10 inches) of annual rainfall grow their own food and produce cotton, dried fruits, and oilseeds for export — achievements made possible by qanats. Until recently (before the Karaj Dam was built), the 2 million inhabitants of Teheran tapped the foothills of the Elburz Mountains with qanats for their entire water supply. The agricultural production made possible by qanats repays the investment cost for construction and maintenance. In 1967 the return on investments from the sale of water and crops ranged from 10 to 25 percent per annum depending on the size of the qanat, the yield of water, and crop. Qanats have their limitations, for they usually flow continuously and year-round, and unused water is wasted. Flow

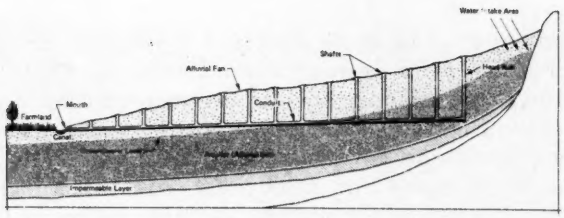
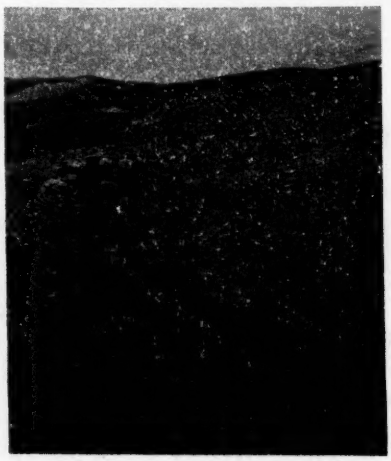


FIGURE 4. Exploiting the gradient of the natural terrain, qanat system is a series of wells dug into an underground water supply and connected by underground channels that convey water by gravity to the ground surface at lower levels.

FIGURE 5. Water flowing out the main qanat of Dusadj village, Iran, is used mainly for irrigation. A qanat can deliver water in otherwise very arid terrain.



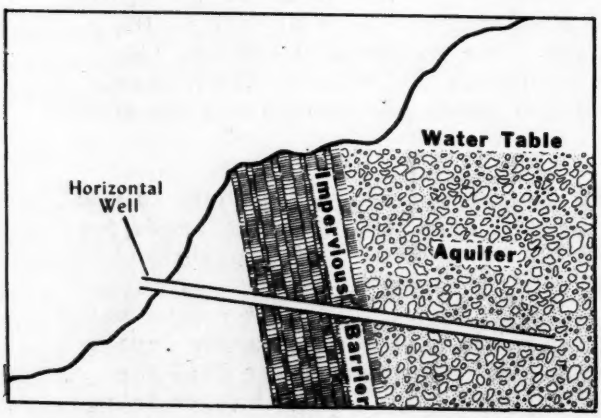


FIGURE 6. Good sites for horizontal wells are dike formations, impervious geologically tilted clay, or rock walls that form a natural dam.

is maximum during the rainy season when the demand for irrigation is least and minimum during the major irrigation period (summer). Qanats may dry up altogether in drought years. They serve the lower elevations of alluvial fans, which tend to have more saline and poorer soils than do the higher elevations. Qanat water is often of poorer quality than water from wells drilled higher in the alluvial fan. Qanats are expensive and dangerous to build by the primative hand-tunneling methods of the past, and in recent years construction costs have increased along with rising standards of living and labor costs. Research is needed on safe construction methods, on qanat linings that increase safety and decrease maintenance, and on ways to shut off the water flow when it is not needed.

Horizontal wells. Horizontal wells are drilled at promising sites where springs, seeps, or traces of water are found. A horizontal boring is used to drill a hole and install a steep pipe into a hillside to tap a trapped water supply. (Figure 6) A horizontal well can tap the aquifer with precision and safety. Furthermore, it protects against contamination by animals, dust, erosion, etc. No pumps are needed. Maintenance costs and problems are insignificant. If the flow is very low, a storage tank can be added to accummulate water during the night or off-season. With adequate storage, spring sites that flow only during a few weeks in the year may be useful.

Horizontal drilling equipment is currently manufactured; it is simple, portable, and dependable. However, horizontal well drilling is quite a different technology from vertical drilling. Skill, patience, and field experience are required to master it.

Groundwater mining. Many productive aquifers in arid regions of the world are storing large quantities of water that can be tapped by well known deep-well extractive techniques. Aquifers of this type are widespread beneath deserts in northern Mexico, southwestern United States, North Africa, eastern Saudi Arabia, the Sinai, and elsewhere in southwest Asia. The water in such aquifers is not naturally replaced once it is withdrawn. Its development must be undertaken with the full understanding that, usually within a few decades, the supply will be depleted.

Desalting

Although new and improved desalting methods using membranes and ion exchange have been developed, no method can yet promise truly low-cost freshwater. Current promises of cost reduction for distillation plants are based on the assumption that the cost of the product decreases as the size of the plant increases. But a practical limit exists to cost reduction achieved by this means. Also, there are problems in disposing of huge quantities of hot brine, pumping and

conveying desalted water to the point of use, and storing it until needed for irrigation. Another fundamental problem is that desalting plants require large amounts of energy to construct and operate. Most proponents of desalting schemes now agree that the water will be too expensive for use in irrigation as practiced today. However, distillation plants producing up to several million gallons per day are commercially available and are already used for domestic and industrial purposes in some very arid regions where the local economy can afford it.

Solar Distillation

In solar distillation the sun's radiation passes through a transparent cover on to a source of brine; water evaporates from the brine; and the vapor condenses on the cover which is arranged to collect and store it. It was first used in Chile's Atacama Desert in 1872 in a plant supplying drinking water for livestock used in nitrate mining. The plant reportedly operated for 30 years. The process today is generally in the pilot stages, though community-scale stills are now used on a small commercial scale to supply small towns in isolated areas of Australia and small communities in the Mediterranean basin and the Caribbean. Modern research into solar distillation is emphasizing new materials and designs for economical and durable construction to reduce product-water cost.

Remote Sensing for Detecting Water

The use of photographs from satellites and high-flying aircraft is a newly developing tool that is proving useful for planners in arid lands. The following are a few successful uses of such remote sensing: Open-water oases have been detected, and repetitive imagery has been used to determine their transience. Geological information for determining the shape and extent of underground aquifers has been obtained from most types of remotely obtained imagery, including radar, thermal, and optical images from aircraft or satellites. The extent of springs, seeps, and shallow groundwater in alluvial channels is often mappable, even from satellites, because trees and shrubs associated with moisture can be detected. Effects of rainstorms on the desert can be detected; after a storm, the darker tones of the moist soil can be seen, and a few weeks later vegetation responding to the moisture is revealed. And plumes of freshwater from offshore submarine springs can be detected with the use of thermal scanners because they usually differ in water temperature from the surrounding sea.

Rainfall Augmentation

Certain cloud formations contain super-cooled water; rainfall augmentation hastens precipitation of this water. Adding ice, frozen carbon dioxide, and silver iodide — whose crystal shapes promote condensation of super-cooled water — causes ice-crystal formation and produces rain.

This method is known as cloud seeding [see Development Digest of January 1972, pp. 79-84]. Though there is keen interest in cloud seeding in arid lands, experience indicates that its best opportunities for increasing precipitation are in areas where cold, wet air masses are swept upward over mountain ranges. Prospects for increasing precipitation over low-lying arid lands do not seem promising, primarily because of the scarcity of water-rich clouds. Arid lands that benefit from cloud seeding will probably be those fed by streams originating in mountains. The results of cloud seeding are very difficult to predict because of the still imperfect knowledge of the physical processes causing precipitation and because of engineering difficulties in getting seeds into clouds in optimum amounts and at the right time and place.

Icebergs

Eighty-five percent of the world's freshwater is trapped as ice in the polar regions, but it is generally considered unusable. Engineers, glaciologists, and physicists are now speculating on whether it could be profitably recovered by towing icebergs to water-short regions. Data on size and distribution of icebergs indicate that the supply is more than adequate, and satellites can be used to select suitable icebergs.

The icebergs are there; the problem is to move them. According to one report, a hypothetical supertug, which could be built with present technology, could tow icebergs up to 16 km long, 3.5 km wide, and 200 m thick. On delivery, the water in such icebergs would be worth hundreds of millions of dollars. But melting losses are important because transit times at reasonable towing speeds may exceed 100 days and water temperatures at the delivery sites exceed 15°C. Detailed calculations and adequate field observations to accurately predict towing speeds and melting rates still need to be done. Two inherent problems are getting the ice to melt at the end of the tow, and pumping the water from sea level into the supply system. Perhaps the ice could provide a "cold sink" for coastal powerplants; thus, waste heat would be utilized for melting ice and the thermodynamic efficiency of the powerplant increased. Critical technology assessment must precede any decision that iceberg harvesting is a realistic, desirable possibility.

PART II: WATER CONSERVATION

Reducing Evaporation from Water Surfaces

Reservoirs and canals in arid lands are subject to heavy evaporation losses, which are often not recognized. Evaporation losses from surface areas open to the air often exceed the amount of water used

productively. Reducing evaporation is an important way to increase the supply of water. It increases reservoir capacity without new construction; in arid regions, it may mean the difference between a dry reservoir and a filled one.

Generally, the method used has been to cover the water surface with a barrier that inhibits vaporization. On small tanks, a cover or roof is an obvious choice, but for ponds and larger reservoirs the solution is less simple. For the latter the methods tested include the following: liquid chemicals that automatically spread out, forming a sealant layer across the surface; blocks, rafts, or beads that float on the water surface and reduce the area where vaporization can occur; and storing the water in sand- and rock-filled dams.

Water coverings. Aliphatic alcohols, e. g. cetyl alcohol, are made up of long slender molecules that align themselves side-by-side on a water surface, covering it to form a film one molecule thick. Unfortunately, the films decrease the amount of heat normally lost from the water and the higher water temperature increases evaporation at the parts of the water surface that the barrier does not cover. Furthermore, an intact alcohol barrier is impossible to maintain because of wind and wave action. Nonetheless, it requires only small amounts of materials; it reportedly does not restrict the transmission of oxygen to the water; and it consists of materials that are nontoxic to fish or human. Attempts are now under way to circumvent the problem of maintaining a continuous film on the water surface by using a plastic net to restrict the drift and disruption of alcohol layers.

Wax is an unusual, recently tested evaporation suppressant. Floating blocks of wax are added to the water; in sunlight they melt and flow to form a flexible, continuous film. In Arizona, a wax cover on a small tank is still in good condition after 4 years; the evaporation suppressing efficiency is over 85 percent.

Floating blocks of lightweight concrete, polystyrene, wax, rubber, and plastic are under trial as evaporation retardants. (Figure 7) In order to overcome the water heating the floats are made of insulating and light-colored reflecting materials that prevent solar energy from entering the water. For example, sheets of inexpensive and highly insulating expanded-polystyrene, 2. 5 cm thick and coated with asphalt and gravel have been tested. Coupled together with inexpensive clamps to form large rafts up to 160 m^2, they can form excellent energy and vapor barriers.

Suppressing evaporation in impounded waters also suppresses the increase in salt concentration that occurs with evaporation. Floating evaporation control materials cut off the light, thereby reducing the growth of undesirable algae and submersed aquatic weeds. At present evaporation suppression is limited to small storage facilities such

as ponds, tanks, troughs, and oases. In practical terms large reservoirs, lakes and rivers are still beyond the reach of available technology because it is very difficult for the evaporation-suppressing system to survive heavy winds, storms, and floods. The effects of evaporation-control methods on animal life in the water may not be important in small containers, but they should be considered in reservoirs.

Evaporation suppression is still experimental. By far the greatest number of studies have been concerned with alcohol films. The use of solid floating materials is limited but appears to offer the most promise for small storages. No economical method exists for reducing evaporation from large, multipurpose reservoirs; research in this area is badly needed.

Sand filled reservoirs. Evaporation can be controlled by filling reservoirs with sand and loose rock. Water is stored in the pores between the particles, and the water level is kept more than 30 cm below the surface to shield it from evaporation. Recently, two small plastic lined tanks were built near Safford, Arizona, and filled with rocks. The rocks reduced the tank's volume by 55 percent, but they reduced evaporation by 90 percent. Small sand-filled dams can store water for long periods, much longer than conventional open storage. They can provide water during years of total drought; when the water table is one m below the sand surface, evaporation ceases for all practical purposes. The water is drawn off by a drainage pipe through the dam wall or by a well dug into the sand. (Figure 8)

The dam wall is built across the riverbed during the dry season; later, the river floods will deposit the necessary sand and gravel. Normally, the soil carried by flood waters is 3/4 sediment and mud and only 1/4 sand and gravel. A dam trapping all of this mixture would quickly silt up. To ensure that only sand and gravel are deposited, the dam wall is heightened in stages of only one meter (though the first is usually about 2 m). Floodwaters deposit the heavy gravels and sand, but silt and soil are carried over the top of the dam by the speeding waters. Each one-meter stage is added when the dam is filled with sand and gravel (which may require a complete wet season) until the operating height of 6-10 m is reached.

Sand dams have been built by the score in Southwest Africa during the past 50 years; a few have also been built in East Africa. However, sand storage dams can be built only where the geology permits. Floodwaters must contain enough gravel and sand, and the dam site must be made absolutely water tight, e. g. cement grouted, to stop seepage if necessary. To build a sand dam requires patience and time because often only one stage can be added each year. For this last reason the technology has not yet been widely accepted.

Reducing Seepage Losses

For economic reasons most arid lands are forced to use earthen canals and reservoirs for moving and storing water. Because the soils are often porous, many of these storage facilities and conduits suffer serious water losses through seepage. Seepage can be reduced if the walls of reservoirs and conduits are made watertight. Recent technology has produced many waterproof materials that may prove valuable for this purpose. Ways to make soils impervious to water seepage include chemical treatment of soil, and soil covers such as butyl rubber, sheet plastic, asphalt reinforced with plastic or fiberglass, and ferrocement.

Much seepage is caused by calcium in the soil. Calcium causes clay to bunch up (aggregate), forming cracks and a porous structure that lets water seep through easily. If the soil is treated with a sodium salt such as sodium carbonate, the sodium breaks up clay aggregates and causes clay particles to swell and plug the soil pores. For this method the soil must have a minimum of 15 percent clay, be at least 30 cm deep, and have the chemical capacity to exchange calcium for sodium ions.

Shallow earthen, but rock-free reservoirs (less than 3 m deep) can be made watertight with low-cost types of polyethylene and polypropylene films, but deeper reservoirs or those built on stony soils require thicker and tougher films of vinyl or reinforced polypropylene. In both cases the films should be protected with a covering of soil or gravel. Concrete-based materials, such as cement-stabilized soil, ferrocement, and concrete-filled fabric also have potential as liners.

One problem encountered in lining reservoirs is stablizing the banks. Soil is usually unstable on slopes greater than 1:3. Steeper slopes are desirable, however, to maximize storage, minimize evaporation losses, and inhibit weeds. Promising methods of providing a revetment to protect steep banks include the use of used rubber tires, ferrocement, and soil cement packed into sausage-shaped plastic bags. Near vertical slopes can be constructed with sausage revetments. Local soil is blended with a small amount of cement and moistened through pinholes made in the plasitc tube. The sausages are stacked in place tightly and allowed to set. (Figure 9)

Any reduction in seepage provides additional water without requiring new equipment or facilities. In some areas reducing seepage prevents associated problems such as waterlogging and salinification of the surrounding soil. Lining canals also reduces maintenance and weed-control problems. However, maintenance of the lining is a constant concern because even small holes can allow large amounts of water to drain away, especially if the surrounding soil is porous.

FIGURE 7. Protective covering of molded, lightweight concrete slabs cut evaporation by an estimated 80 percent in full-scale tests on two reservoirs in Ovamboland, South-West Africa.

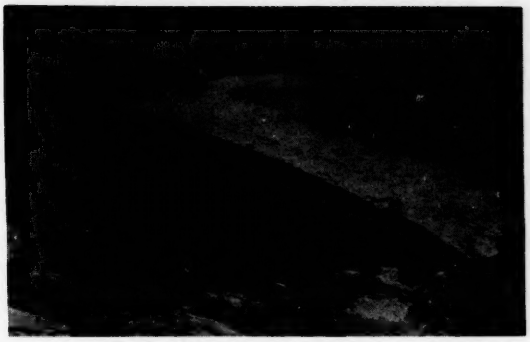
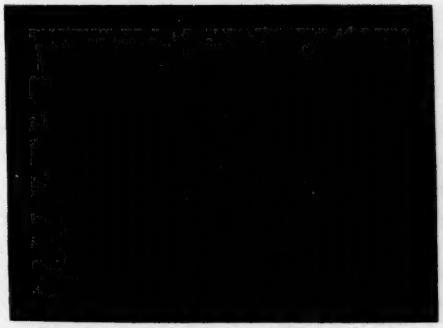


FIGURE 8. Sand dam in South-West Africa built of rock and mortar.

FIGURE 9. Catchment tank at Palapye Central School, Botswana, paved with mud and flat stones and sealed with a plastic liner. Revetment is made of "sausages" thin-plastic tubes filled with soil containing a small amount of cement. Tubes are then pricked with nails and placed in a shallow pan of water. Before the cement sets the tubes are stacked in place. No formwork is needed; the soil-cement is self curing. The sausages are a modern, cheap, do-it-yourself technology.



The primary disadvantage of seepage control is its cost. New, more economical materials are needed, for they could make seepage control possible worldwide. As new watertight membrane materials become available, their use in this application should be evaluated.

Reducing Evaporation From Soil Surfaces

Evaporation from soil surfaces wastes large amounts of water; one-fourth to one-half of the water lost from a crop is evaporated from the soil surface. Suppressing evaporation from the soil conserves water where its effect is great: within the root zone of the plant. Small water savings here may be more important to a crop's survival than large improvements at earlier points in the water supply.

Losses can be reduced and irrigation water saved by placing watertight moisture barriers or water-retardant mulches on the soil surface. These barriers will also stabilize loose soils, stop desert encroachment, allow runoff agriculture, or reduce salinity buildup.

Some soil-surface moisture barriers are made of nonporous materials such as paper, asphalt, latex, oil, plastic film, or metal foil. (Figure 10) A 5-25 mm thick layer of porous material serving as a mulch can also substantially reduce evaporation. Water and water vapor move so slowly through a dry, porous material that soil moisture is retained. Suitable porous materials for mulching are plant residues such as straw, sawdust, wood bark, or cotton burs, as well as gravel, sand, or cinders.

Planting directly into the standing residue of a previous crop is one way to retard evaporation (and reduce erosion) because the residues and the hard unploughed soil surface provide a better moisture barrier than the loose surface left after ploughing. This is known as minimum tillage. Because weeds that would normally be buried by the plough become more of a problem, stringent weed control with herbicides or hand pulling is essential for its success.

Plant residues such as straw and cotton burs retard evaporation. The residues should cover 90 percent or more of the soil surface. The amount of crop residue needed for this is about 1.5 tons/ha in the case of straw and 11 tons/ha for cotton burs. For residues spread on the soil surface, the greatest reduction in evaporation comes with the first 5 mm of thickness. Gravel mulches, in layers as thin as 5-10 mm, reduce erosion by wind and water. The chief problems are cost, the need to periodically redeposit the gravel on the surface, and interference with mechanized planting and cultivation.

Paper and polyethylene plastic mulches control weeds, increase soil temperature, and speed up plant germination and growth. Their use

specifically to retard evaporation in arid regions is now being researched. Yields of irrigated corn per unit of water evaporated and transpired have been nearly doubled in one experiment where the soil was covered with plastic film, indicating that up to half the water used by unmulched corn may be lost through evaporation from the soil surface. Latex, asphalt, and oil mulches have been tested in specific desert situations for their ability to conserve soil moisture, to concentrate rainfall in depressions around plants, and to suppress the movement of wind-driven sand long enough for plants to get established. By retaining the heat absorbed during the day, they can also keep desert soils warm during cool nights. This increases the chances of survival for plants whose roots must otherwise withstand large daily temperature fluctuations. (Figure 11)

For most man-made mulches, the prime limitation is cost. Treating soil with chemicals or covering it with plastic sheets is not cheap. Today, these treatments are suitable only for intensive agriculture of high-income crops such as pineapple and strawberries, or where a complementary feature such as stabilizing sand dunes adds significant economic benefits. The costs of chemical and plastic mulching may also be justified in locations where soil erosion can be inhibited.

The main disadvantage of plant residues as mulches is their relatively short lifetime. They are also difficult to keep in place in windy weather. Plastics, on the other hand, deteriorate slowly and may interfere with the planting of subsequent crops. Gravel and rock mulches are not moved by wind, and they allow rainfall penetration, but they may be expensive to install and can interfere with tillage operations.

Hydrophylic soil amendments. Hydrophylic (water-attracting) chemicals can absorb water, holding it safe from evaporation or further dissipation. Soil mixed with such chemicals becomes sponge-like, trapping and retaining water for an extended period. The water is then available to plant roots which can draw on it as required. This method can be particularly important for increasing available water in sandy soils. Used as soil amendments, hydrophylic chemicals can enhance plant growth at low moisture levels. Plant roots and root hairs grow into and around the water-swollen hydrophylic material and extract water and nutrients from it.

Hydrophylic chemicals have been developed that can absorb up to 20 times their own weight of water. Although one such hydrophylic compound is being test-marketed in the United States, they are still basically experimental. The water-holding capacity of sandy soils can also be improved by incorporating about 5 percent of crushed brown coal into the surface layer. This can double the available moisture, promote uniform soil temperatures, and mature crops earlier.

The very recent development of hydrophylic starch copolymers that absorb water up to 1,500 times their own weight has been reported. Their role in arid-land agriculture remains to be tested.

Trickle Irrigation

A newly developed irrigation system, known as "drip" or "trickle" irrigation, uses a system of plastic pipes placed among the plants on or under the soil. (Figure 12) Water carried in the pipes drips onto the soil through outlets arranged near each plant; because only a small amount of the soil is watered, evaporation losses are minimized. Furthermore, the rate and time of water application are adjusted for no runoff and minimal deep percolation losses. Trickle irrigation is already used extensively on tree, vine, and row crops, but because of high costs it is not yet used much for field crops. It has particular promise for slopes or rocky areas where land leveling for conventional irrigation is prohibitively expensive.

In trickle irrigation small amounts of water are applied at frequent intervals to a specific site near each plant. Under each site a wet area is formed, that extends to the plant's roots. The application can be adjusted to replace water continually as it is used up by the plant. To conserve energy and minimize flow rates, trickle-irrigation systems are normally operated at relatively low pressures. Basic equipment for trickle irrigation consists of a water-supply head, delivery pipes, manifolds, lateral hose lines, and emitters, along with control valves, couplings and filters. For more highly controlled and mechanized applications, timeclocks, fertilizer injectors, gauges, etc. may be used. Since the water passes through very small outlets in the emitters, it is important that it be screened, filtered, or both before it is distributed in the pipe system.

Trickle irrigation gives much greater control over the placement and amount of water. Thus, unlike other irrigation methods, trickle irrigation minimizes surface standing water, which can breed mosquitoes and increase water-logging and anaerobic soil conditions that adversely affect plant growth. Trickle-irrigation equipment costs must be judged in comparison with the expensive land preparation (and continued land maintenance) often required by surface irrigation. Land leveling, and canal and drain digging, require a considerable infrastructure which is dispensed with in a trickle-irrigation system. The potential cost savings may be large. And fertilizers can be applied through the trickle system, efficiently applied close to the roots.

Trickle irrigation has proved most effective for permanent tree and vine crops. In many standard situations, however, it may be less appropriate than conventional methods, and there are some serious technical problems with trickle irrigation. The primary problem

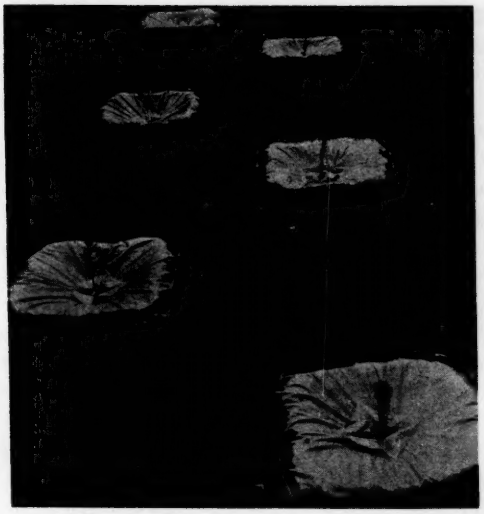


FIGURE 10. These plastic "aprons" are being evaluated to determine their ability to catch rainfall, reduce evaporation, suppress weeds, and promote the growth of tree seedlings in arid areas.

FIGURE 11. Consistency of sand stabilized with an oil/latex mulch. Sealed surface reduces evaporation losses and holds the sand in place long enough for plants to become established.

FIGURE 12. Trickle irrigation, showing the areas wetted by individual drippers attached to the plastic pipes.

is clogging of the emitters which can be eliminated by careful management, filtration, and chemical treatment, but this increases operating costs. At present, trickle irrigation cannot be used with iron-containing water. Algae are normally removed by chemical treatment followed by filtration. Methods for removing fine sand, silt, and clay are still inadequate, especially where large amounts of suspended material are encountered. In addition, careful control during construction and maintenance operations is essential to stop particles entering the system. With trickle irrigation as with other methods, careful management and expert advice are essential when saline waters are used.

Reducing Cropland Percolation Losses

Millions of tillable hectares of sandy soils, widely distributed throughout our arid regions, have low productivity due to an inability to prevent water from percolating away too rapidly for plant growth. Growing crops in sandy soils thus requires frequent irrigation; in many arid regions this is not practical, particularly if rainfall provides the only water. Techniques have been developed to produce artificial underground moisture barriers that keep water and nutrients from percolating below the root zone, and by retaining more water in the root zone the barrier can create a soil suited to crop production.

Underground moisture barriers are continuous films of a water-resistant material placed approximately 60 cm below the soil surface with gaps every 150 m or so for drainage. Although most barriers have been made of asphalt, any durable water-impervious material like plastic sheets, or layers of compost or manure can be used. The optimum depth for the barrier depends on the moisture-holding characteristics of the sand. Drainage considerations determine the extent of the barrier.

One way to install a barrier is to remove the topsoil, hand-place the moisture barrier, and then refill the area. But machines have been built that will install a waterproof asphalt barrier without excavation. A wide, wedge-shaped plow pulled through the ground at 50-70 cm below the surface lifts the soil, and nozzles spray asphalt into the cavity. The asphalt immediately hardens into a moisture-proof layer 2-3 mm thick before the earth falls back in place.

Unlike many other soils, sand has a surface durable enough to withstand the abuses of tillage and farming; it allows quick intake of rainfall or irrigation water; its good capacity for aeration favors root development; and its upper layers often serve as a mulch, reducing losses from evaporation. When its low capacity for retaining water is corrected, sand can become highly productive. A barrier under

the surface gives sandy soil a storage capacity equivalent to that of a better agricultural soil in a temperate region. Thus, barriered soils require less frequent irrigation than unbarriered soils and can save 50-75 percent of irrigation water.

Today, the cost of underground moisture barriers is high — largely due to the cost of the barrier material (asphalt may be cheap in oil-producing countries however). To install a barrier in the United States using the mechanized system costs $625-$750/ha. It can be used only where the soil is otherwise useless, where high-value crops can be grown, or where water is in short supply and farm production is badly needed. Under present conditions underground moisture barriers are economically feasible in many areas of the world, but only for high-profit crops. Deep roots penetrate moisture barriers but do not continue growing in the water-deficient soil below them. Crops with deep roots, especially tap roots, could, however, eventually perforate the barriers and reduce their efficiency.

The biggest technical problem in producing a moisture barrier is to seal the joints between successive strips, particularly in barriers laid by mechanized systems. The question of whether salinity builds up in the soil because drainage is retarded by an underground moisture barrier is not completely answerable today. Since no barrier yet built has been completely watertight, drainage has leached the salts away and kept them within acceptable levels. In some cases, however, a certain amount of irrigation water must be reserved solely for leaching.

Reducing Transpiration

Only one percent of the water absorbed by roots is incorporated into the plant cells; 99 percent moves up through the plant and passes into the atmosphere as water vapor. This process, called transpiration, differs from evaporation in that it takes place on living tissue and is influenced by the physiology of the plant. One ha of growing vegetation can transpire as much as 94,000 liters of water per day. If a practical way to reduce transpiration could be found, substantial reductions in water demand could be achieved.

Transpiration losses can be reduced in several ways: 1.) Destroying unwanted phreatophytes — plants that transpire efficiently. Phreatophytes, such as salt cedar and mesquite, often have roots that penetrate groundwaters at great depth and the groundwater losses they cause are not widely recognized; 2.) Reducing air movement over a crop, for example, by interplanting rows of taller plants to make windbreakers; 3.) Removing unproductive leaves physically or with defoliants. In crops such as wheat and barley, upper leaves contribute most to the developing grain. Removing the lower leaves, if properly

timed, can reduce water lost by transpiration with little or no loss in grain yield. 4.) Using chemical antitranspirants.

Transpired water is passed out of the plant through stomata — pores in the leaf surface through which carbon dioxide, oxygen, and water pass. The opening and closing of stomata are caused by two highly specialized guard cells surrounding the aperture. Several chemicals can prevent complete opening of the guard cells, thereby decreasing the loss of water vapor from the leaf. Most promising of these are certain alkenylsuccinic acids and abscisic acid, which are sprayed onto the stomata-bearing surfaces of the leaves (usually stomata are concentrated on the undersurfaces) to inhibit water passage. Although the technology is embryonic, present antitranspirants have reduced water losses by 40 percent in some experiments. (Figure 15) The frequency of spraying depends on the antitranspirant's durability and the rate at which new foliage is produced. Present evidence indicates that most antitranspirants may be effective 1-4 weeks, although some reductions in transpiration have been observed over several months.

Leaves can be covered with films that form transparent barriers to the escape of water vapor. Materials tried as antitranspirants include cetyl alcohol, silicones, wax, latex, and plastics. Alternatively, reflecting materials sprayed on leaves reduce the solar energy absorbed and lower leaf temperature, and therefore slow down transpiration. Reflecting materials do not normally need to block stomatal pores on the undersurface of leaves; they interfere less with oxygen and carbon dioxide transfer than do the other chemical antitranspirants.

There are limitations on reducing transpiration water losses. Destroying phreatophytes is very controversial; it may disrupt the always-fragile arid environment. Stomata serve as portals for the intake of carbon dioxide necessary for photosynthesis and growth; thus, a chemical barrier against water loss may reduce plant growth if it also interferes with the passsage of carbon dioxide. Today's chemical- and film-forming antitranspirants do restrict carbon dioxide movement and, thus, are most useful where water conservation is so important that maximum plant growth can be sacrificed. Some antitranspirants are toxic to some plant species and should be used with care. Present antitranspirants affect only the leaf surface to which they are applied and therefore are of little use on rapidly growing crops whose leaf surfaces are expanding rapidly.

Transpiration reduction is mainly experimental today. Although great potential exists, basic research on antitranspirants has so far been meager and not overly encouraging for their widespread use. Reflectant materials have been tried on artichokes in Israel with considerable success: the percentage of cuttings that rooted increased

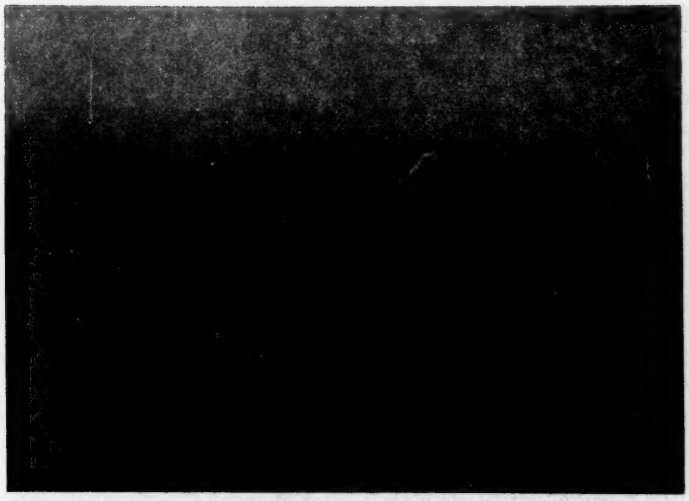


FIGURE 13. Aerial view of 500 acres of sprinkler-irrigated alfalfa and barley in pilot farm on desert land in Libya which never before supported plant life until Occidental's discovery of water.

FIGURE 14. Pitcher irrigation, a new development, uses unglazed baked earthen pitchers, which are widely available and very cheap in many developing countries. The pitcher is buried to its neck in the soil and filled with clean water. Vegetable seeds are planted around it. Enough water soaks through the porous pitcher into the root zone to maintain plant growth.

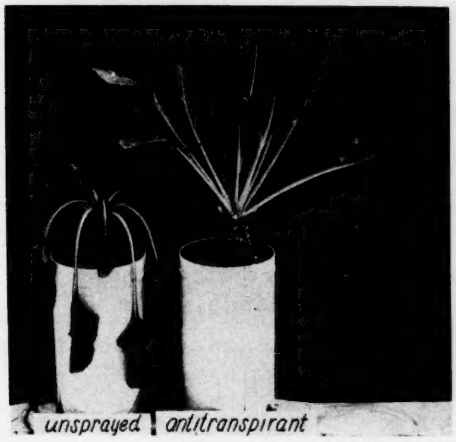


FIGURE 15. Matched sugar-beet plants, one treated with an antitranspirant, were irrigated to saturation and then allowed to grow without further water. Three days later the treated plant still retains its moisture and turgor, the other has wilted.

greatly; vegetative growth was improved; and higher yields were obtained.

Selecting and Managing Crops to use Water More efficiently

A breeding program aimed at developing cultivars (varieties) for agricultural use under arid conditions can be approached (1) by selecting wild plants that now survive in desert conditions and putting them to use as food or cash crops; or (2) by selecting individual water-efficient plants from varieties of already-domesticated crops such as barley, sunflower, melons, sorghum, pearl millet, and beans, and using them in breeding programs. Some characteristics of varieties surviving with a marginal water supply are: plants that grow in cool seasons when evaporation rates are lower; rapid-growing plants that shorten the time in which water is lost by transpiration and evaporation; high-yielding plants that require no appreciable increase in water supply, for example, the short-strawed wheat varieties evolved in Mexico that give double or triple the yield of older wheat varieties without increasing water demand and can double or triple water-use efficiency; plants that can tolerate low-quality saline water; and plants with low transpiration losses. For example, agave and pineapple close their stomata during the day when evapotranspiration losses are greatest; they consume less water than do plants that open their stomata during the day.

Drought is unquestionably the most important environmental factor influencing the growth of plants in the arid regions of the world. The small amount of rain in arid lands is intermittent and unpredictable; any arid-land crop has to survive droughts. Various characteristics, such as deep, well-branched roots, can be used as selection guides for plants that are drought resistant, but the basic physiology of the drought-resistance process in plants is complex and little studied. Genetic improvements take much time; however, selection of species, varieties, and ecotypes of most efficient water use may be important enough to justify active investigation. Cultivars and ecotypes must be selected not only for their water-use efficiency but also for their hardiness and drought resistance.

Managing plants for water-use efficiency. In arid lands water supply is often not the major factor in crop yield; sometimes the crop's environment is the leading cause of inefficiencies in water use. For example, cultivation practices must reflect the importance of helping the plant's root system to extract meager moisture from arid soils. Practices that increase the rooting volume of the soil will improve yields and water-use efficiency. On the other hand, practices that interfere with roots may have adverse effects in arid lands, even if they are successful in temperate climates.

Cultural practices that result in overgrazing also reduce water-use efficiency by restricting the depth and ramification of the grass roots. Part of the reduction in yield experienced on overgrazed ranges may be due to a lack of sufficient vegetation to hold the rain and snow that fall. Thus, pasture and range management practices that minimize runoff and maximize infiltration use available precipitation more efficiently. Cultivating crops in rows on the contour increases the infiltration of rainfall and reduces water and soil losses. Thorough weed control in fallowing operations facilitates water storage by eliminating transpiration losses. Leaving crop residues as a mulch also conserves water.

Controlled-Environment Agriculture

By encapsulating crops within specially developed enclosures, high agricultural productivity can be achieved with limited amounts of water. Water normally lost by seepage, evaporation, and transpiration is retained and reused within an enclosure which may be transparent fiberglass structures, air-inflated plastic bubbles, or low tunnels over the row of growing plants. Within the enclosure light, heat, water, humidity, carbon dioxide, nutrients, and pests are manipulated and balanced to produce yields often ten times larger than those of conventional outdoor agriculture. With special techniques most of the water can be low-quality water otherwise unsuited to agriculture. In essence, this method places crops in an environment that can be so controlled that the upper limits of their yield potential are approached. (Figure 16)

In one closed-environment system pioneered by the University of Arizona's Environmental Research Laboratory and the University of Sonora, Mexico, plants are grown in inflated plastic greenhouses in which there is little or no connection with the outside atmosphere. Inside, the air is continuously cycled through a stream of water which humidifies and cools it. Brackish, silty, or even sea water can be used when the water does not touch the plants or soil; the humidification process leaves contaminants behind.

For photosynthesis to occur, carbon dioxide (CO_2) must be added because in the closed environment the plants quickly use up the available CO_2. In Puerto Penasco, Mexico, scrubbed diesel-generator-exhaust gas, containing large amounts of CO_2, is introduced into the enclosure. Research to date shows that this apparently simple technique has promise, but problems remain, especially in removing minor contaminants that reduce crop production.

In a partially-open-environment agriculture system, fresh air is continuously supplied to the interior of the enclosure and returned to the outside atmosphere. The air is passed through a stream of water

which can be of low quality. High-quality water is used for irrigating the crop, but because the high humidity suppresses evaporation and transpiration, the amount needed is still far less than that for standard agriculture.

One novel modification of controlled-environment agriculture uses low plastic tunnels placed over the plants (Figure 17) to reduce evaporation and transpiration losses. According to one report, carbon dioxide added to the tunnels caused cucumber plants to develop more quickly, to fruit earlier, and to yield up to 45 percent more than in standard agriculture. Lettuce gave a similar yield increase, and sweet peppers set more fruit and gave a 20 percent increase in yield. In Israel in 1966-67 over 1,200 ha were grown under such plastic covers. This method made it possible to produce vegetables very early in the season when supplies from conventional agriculture were meager and prices high.

Impressive productivity has been obtained in controlled-environment systems. Annual per-ha yields of 370 tons of tomatoes and 600-750 tons of cucumbers have been obtained, and it is possible to grow three to eight lettuce crops per year. Sixteen vegetables and flowers are commercially produced at the controlled-environment-agriculture facility in Abu Dhabi. Although large quantities of water may be needed, the system offers very significant water savings in terms of the size of crop produced.

The major limitation to closed-environment agriculture is the high initial capital investment. Based on University of Arizona experience, complete facilities, including culturing equipment, packing facilities, etc., cost approximately US$250,000-US$370,000 per ha. The tunnel-enclosure system is much cheaper, but it, too, is expensive compared to costs of standard agriculture. This means that only high-value crops can be grown at present. Water is still needed for cooling; hence installations will be limited to coastal areas or locations where water unsuitable for regular irrigation is available. The closed-environment and partially-open-environment processes are now beginning to be commercialized. They are a very recent development, and only a few facilities are now in operation but more are under consideration.

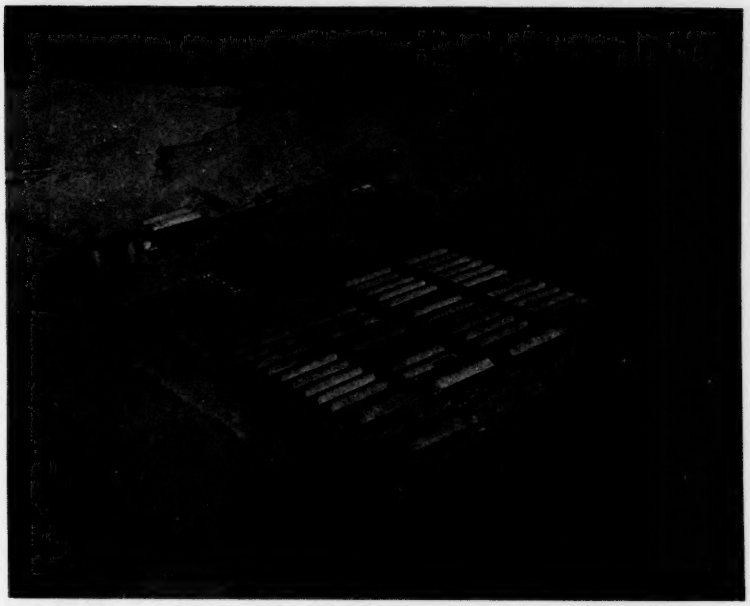


FIGURE 16. Controlled-environment complex in Abu Dhabi. Even in such inhospitable terrain very large quantities of agricultural produce can be produced.

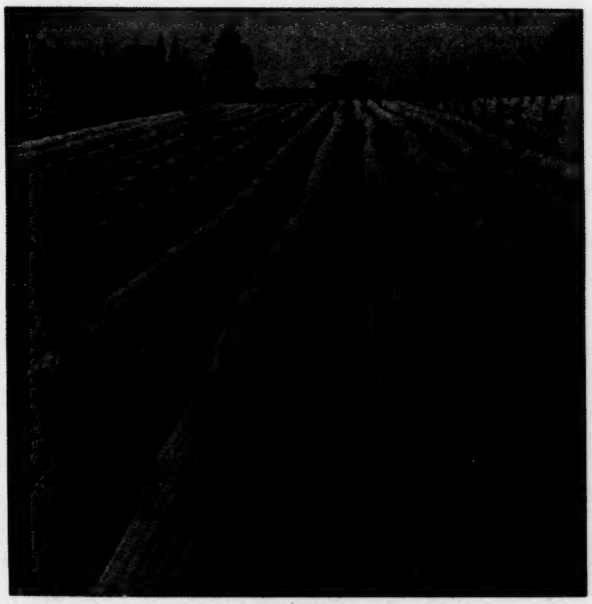


FIGURE 17. Tunnel-enclosure for strawberries grown in Israel.

[Extracted from More Water For Arid Lands, Board on Science and Technology for International Development of the National Academy of Sciences, National Research Council, Washington, D. C. 1974.]

Note: The original booklet, containing references to the scientific literature and addresses of institutions to contact for more information, can be obtained from:

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